

احجز مكانك واستعد للامتحان بثقة كاملة

$$F = \frac{Gm_1m_2}{r^2}$$

ملزمة الفيزياء الفصل الثالث

2026 Inspire 9 متقدم لعام

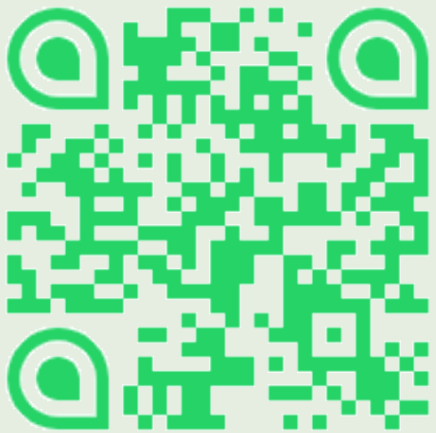
$$EF = ma$$

$$EF$$

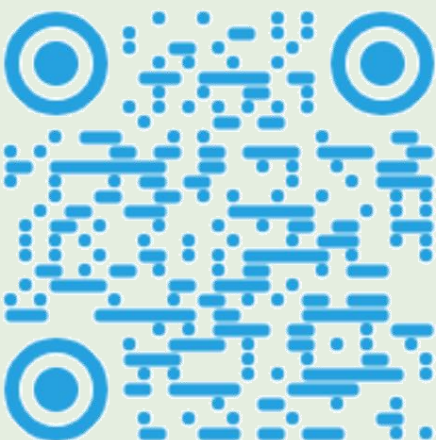
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اضغط هنا: 0566410429

تنويه:
تم إنشاء هذه الملزمة لمساعدتك، ولكن المرجع الرئيسي هو الكتاب،
وسيكون هناك ملف إضافي للأمثلة.



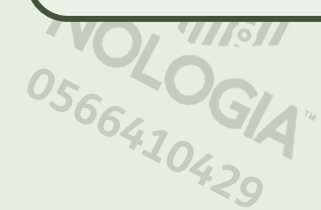


للتواصل والحجز



انضم للقناة

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شرح لدروس الفصل
الثالث كامل

ب. 99
درهم فقط

ملازم

اختبارات



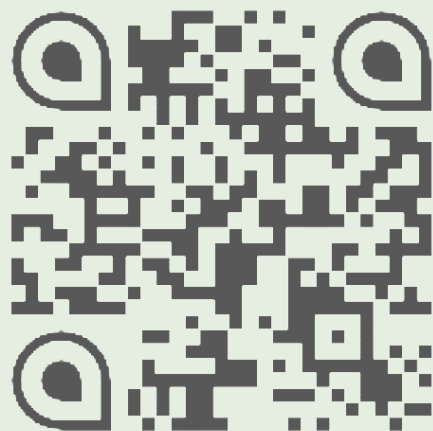
Module (13): Vibrations and Waves

	Lesson Title	Page
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13-3	Wave Behavior	20



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Module (13): Vibrations and Waves

02

Second Lesson: Wave Properties



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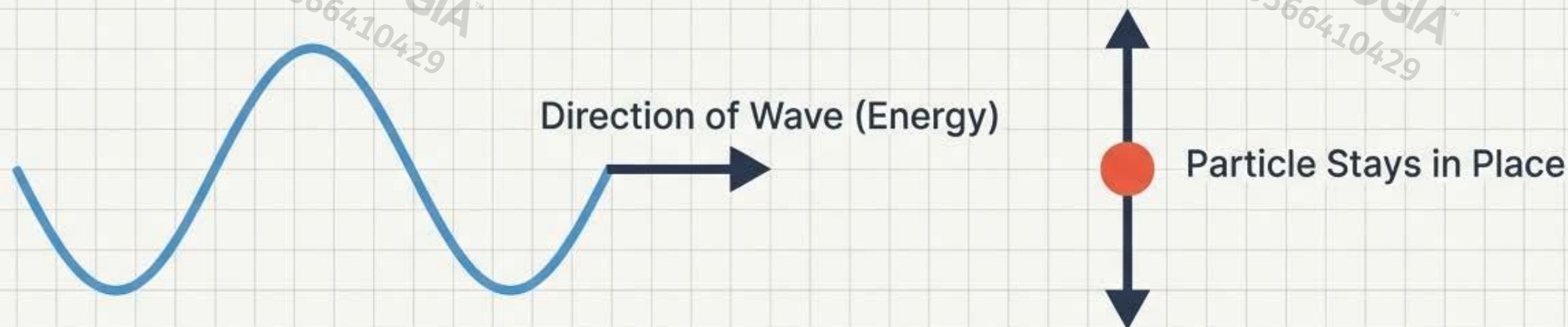


Wave Properties & Mechanics: The Complete Master Guide

Comprehensive Theory, Formulas, and
Real-World Application Examples



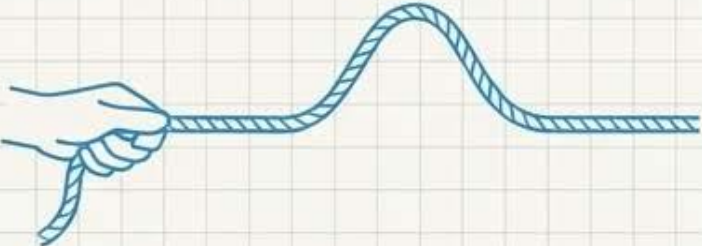
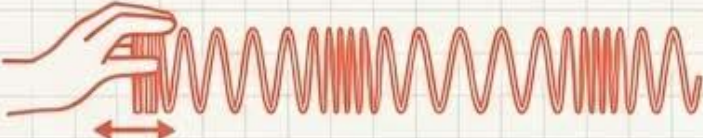
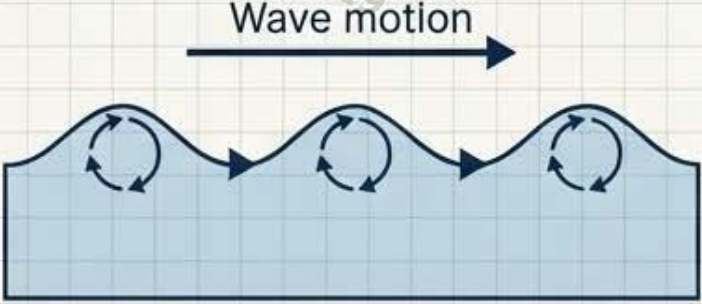
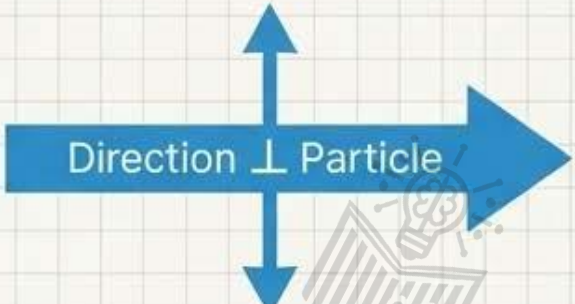
The Core Concept: Transporting Energy, Not Matter



Definition: A wave is a disturbance that carries energy through matter or space without transferring the matter itself.

Key Condition: Mechanical waves (like water, sound, or waves on a rope) require a physical medium to travel through. **Newton's** laws and conservation of energy govern their behavior.

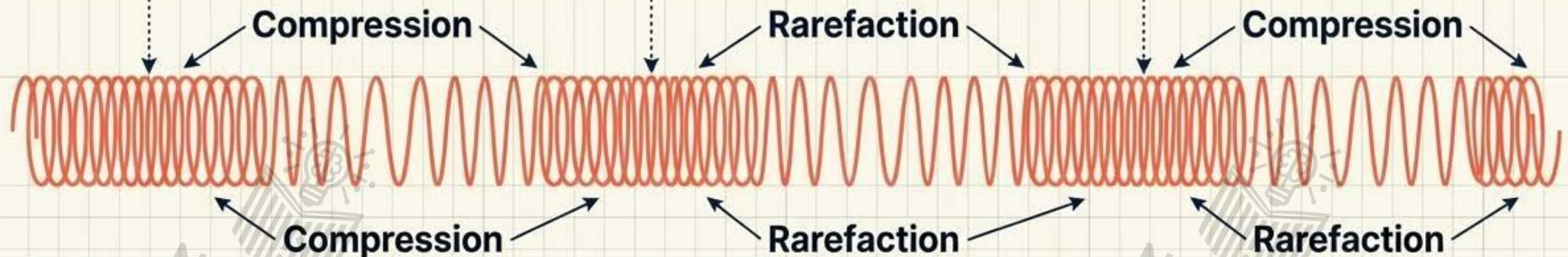
The Wave Taxonomy Matrix

Transverse Waves	Longitudinal Waves	Surface Waves
		
 Direction $\perp$ Particle Particles are disturbed perpendicular to the direction of wave travel.	 Direction $\parallel$ Particle Particles are disturbed parallel to the direction of wave travel.	 Circular Path Particles follow a circular path (both parallel and perpendicular), typical in deep lakes or oceans.

Anatomy Mapping: Transverse vs. Longitudinal

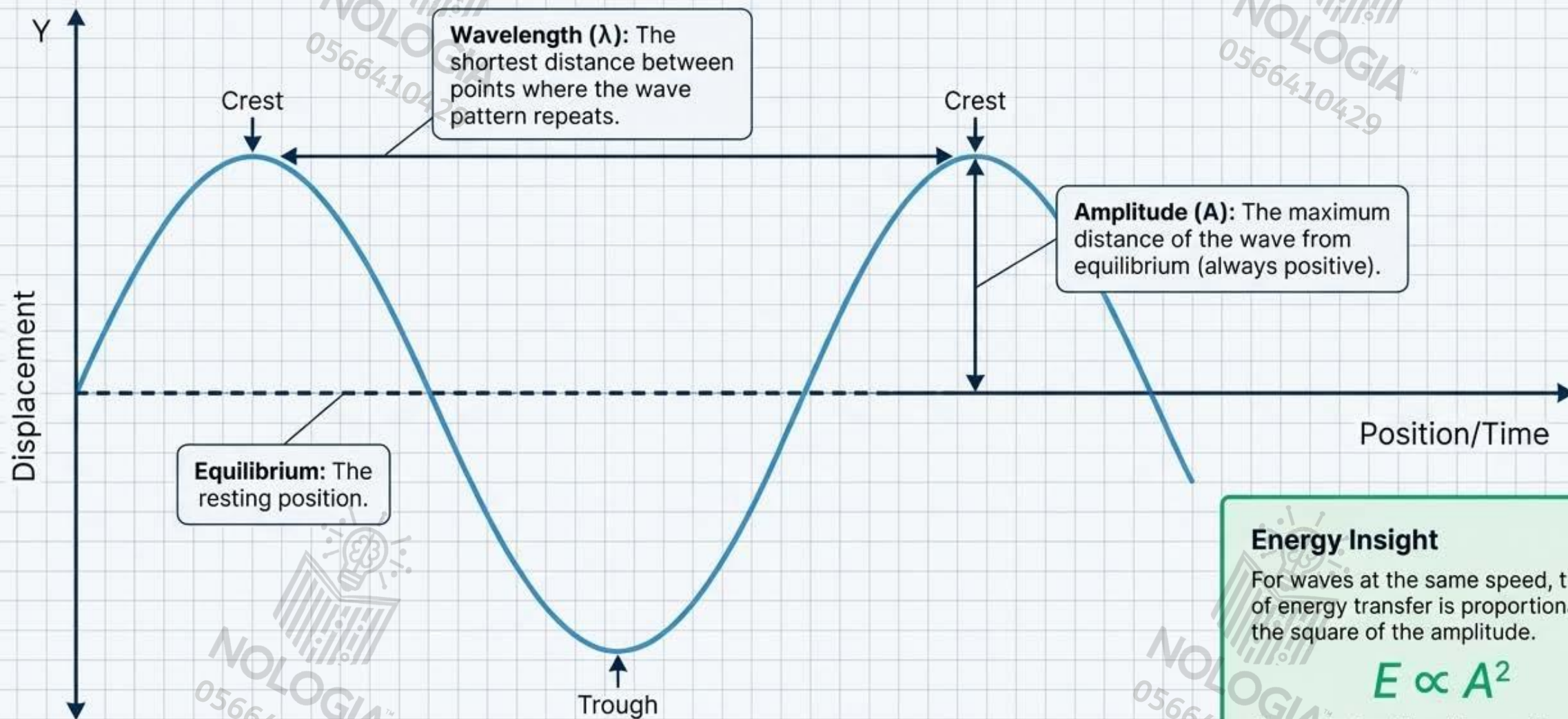


Transverse Waves: Features a Wave Pulse (single bump) or a Periodic Wave. High points are Crests; low points are Troughs.



Longitudinal Waves: Molecules are alternately compressed or decompressed. Areas of high density are Compressions; areas of low density are Rarefactions.

The Master Anatomy of a Periodic Wave



Energy Insight

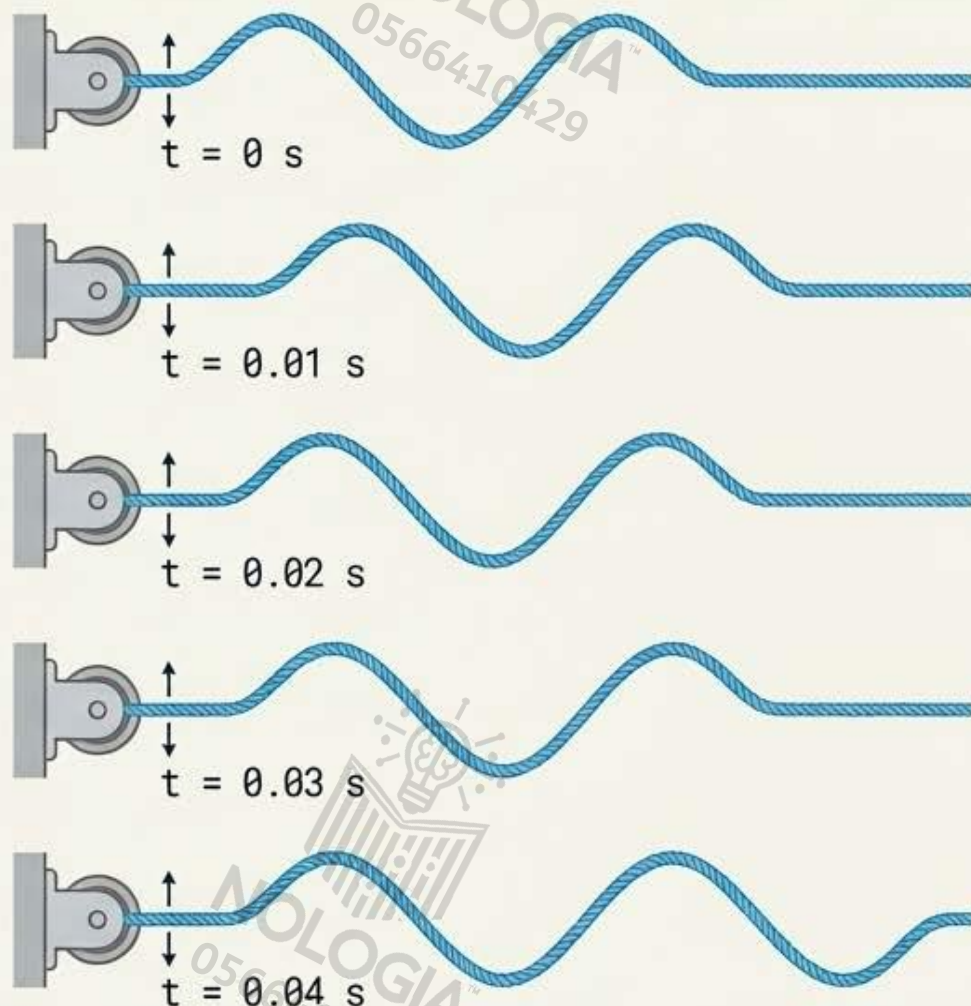
For waves at the same speed, the rate of energy transfer is proportional to the square of the amplitude.

$$E \propto A^2$$

Example: Doubling the amplitude increases energy by a factor of four.

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The Mechanics of Time: Phase, Period, and Frequency



Phase

Any two points one or more whole wavelengths apart. They have the same displacement and velocity.

A crest and a trough are 180° out of phase.

Period (T)

The time it takes for the source's motion to complete one full cycle.

Applies only to periodic waves.

Frequency (f)

The number of complete oscillations a point makes each second. Measured in Hertz (Hz).

$1 \text{ Hz} = 1 \text{ oscillation/second}$.

The Formula Ecosystem

Time Connection

$$f = \frac{1}{T}$$

Frequency is the reciprocal of the period. Both depend only on the source, not the medium.

Velocity Definition

$$v = \frac{\Delta d}{\Delta t}$$

Speed equals distance divided by time interval.

The Master Wave Equation

$$\lambda = \frac{v}{f}$$

often written as: $v = f \cdot \lambda$

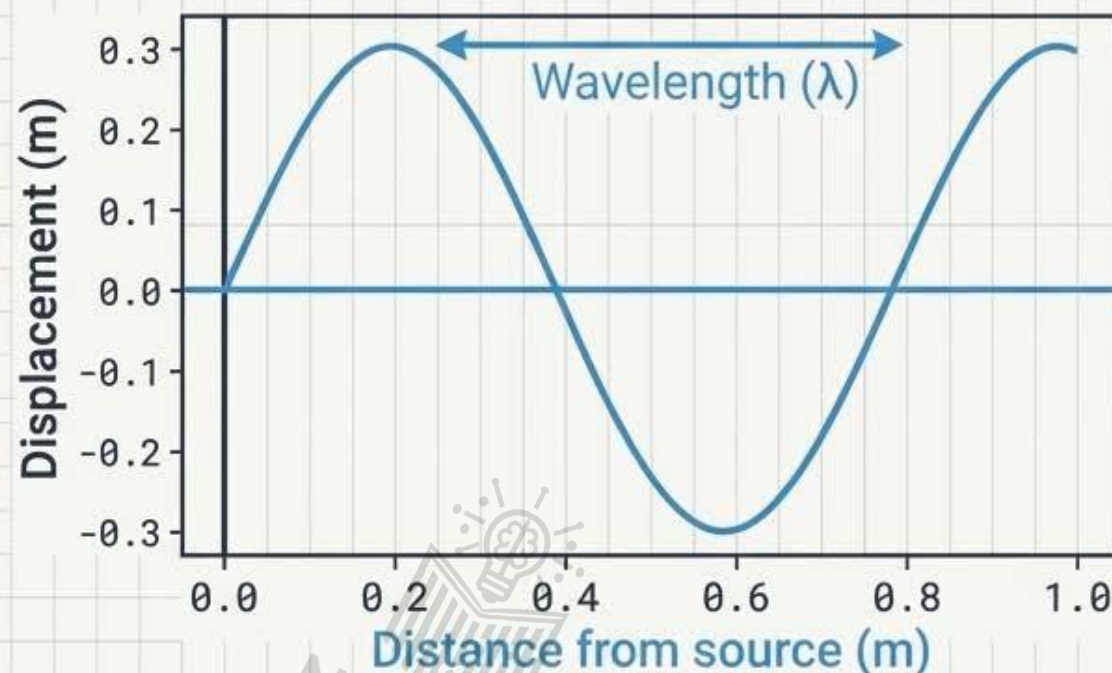
Wavelength equals velocity divided by frequency.

Memorize these three relationships. They are the keys to solving any wave mechanics problem.

Graphing Waves: Decoding the X-Axis

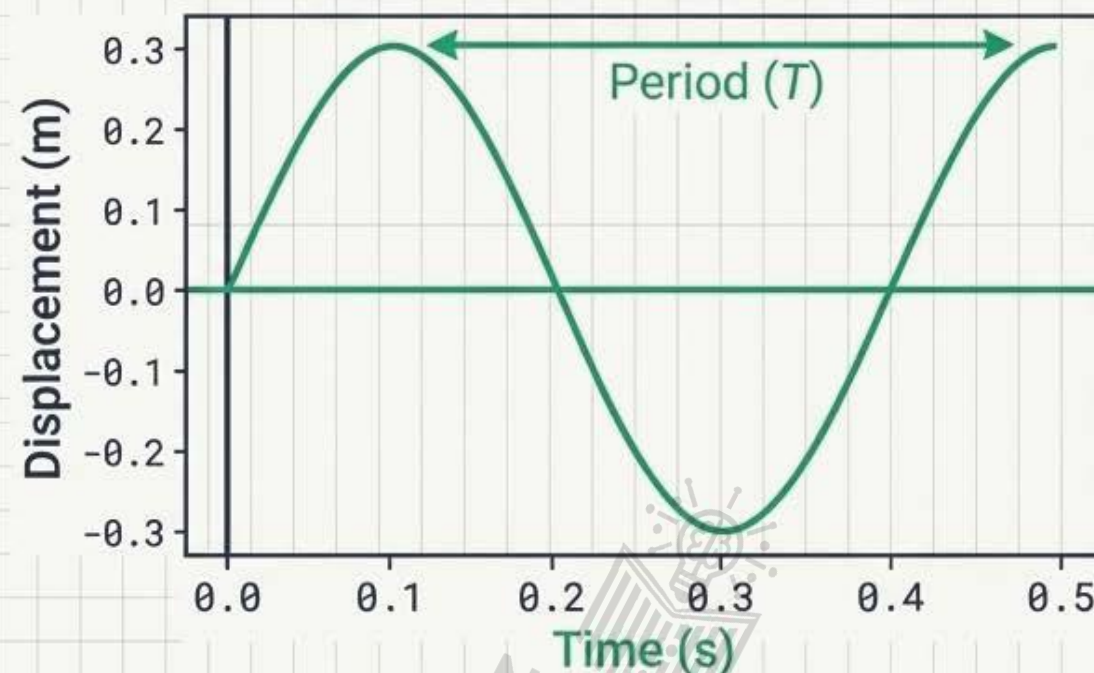
Warning: A wave's shape looks identical on both graphs, but the data extracted is entirely different.

Displacement vs. Distance



A physical snapshot in space.
Yields Amplitude and Wavelength.

Displacement vs. Time

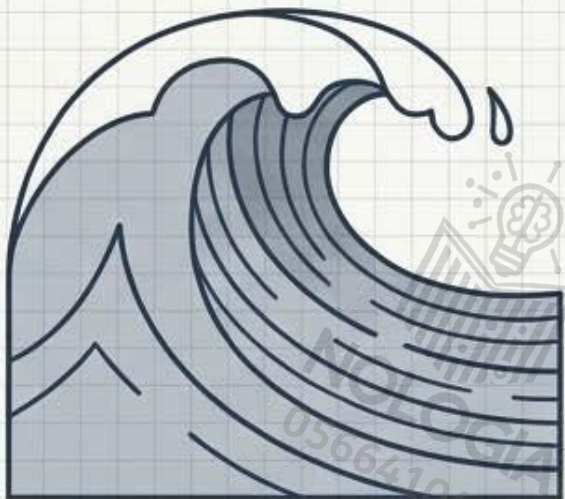


The motion of a single particle over time.
Yields Amplitude and Period.

Real-World Physics: What Controls Speed?

The Golden Rule: For most mechanical waves, wave speed depends only on the medium through which it passes, not on amplitude, frequency, or wavelength.

The Tsunami Example



March 11, 2011, Japan.

Wavelengths > 100 km.

Speeds of
500–1000 km/h.

Why so fast? The deep
ocean medium.

Sound Waves



Speed varies by medium
state and temperature.



Sound travels faster in water
than air.



Sound travels faster in warm,
dry air than in cool, dry air.

Master Example 1: The Stadium Sound Wave

The Problem: A sound wave has a frequency of 192 Hz and travels the length of a football field, 91.4 m, in 0.271 s.

1. Extract Data

Knowns:

$$f = 192 \text{ Hz}$$

$$\Delta d = 91.4 \text{ m}$$

$$\Delta t = 0.271 \text{ s}$$

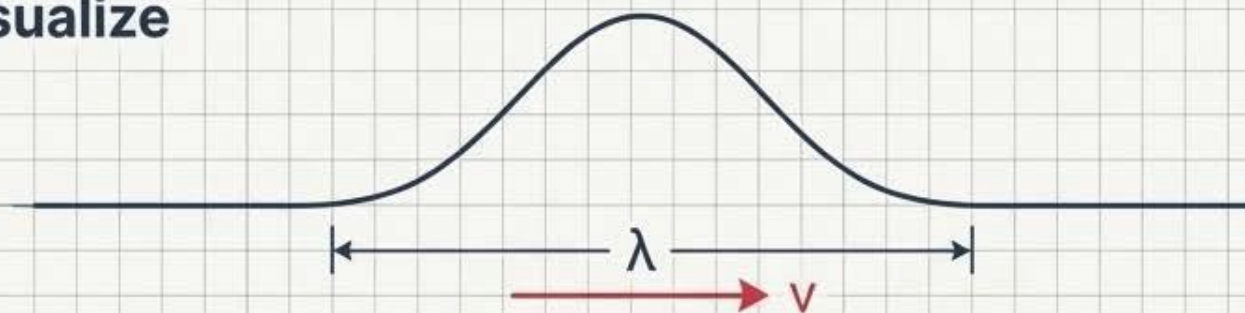
Unknowns:

$$v = ?$$

$$\lambda = ?$$

$$T = ?$$

2. Visualize



3. Execute - Phase 1

Step A: Find Speed. Use the definition of velocity.

$$v = \frac{\Delta d}{\Delta t}$$

$$v = \frac{91.4 \text{ m}}{0.271 \text{ s}}$$

$$v = 337 \text{ m/s}$$

Master Example 1: Wavelength & Period

Step B: Find Wavelength

Use the relationship between velocity, frequency, and wavelength.

$$\lambda = \frac{v}{f}$$

$$\lambda = \frac{337 \text{ m/s}}{192 \text{ Hz}}$$

$$\lambda = 1.76 \text{ m}$$

Step C: Find Period

Use the relationship between period and frequency.

$$T = \frac{1}{f}$$

$$T = \frac{1}{192 \text{ Hz}}$$

$$T = 0.00521 \text{ s}$$

Evaluation Check

Are magnitudes realistic? Typical sound wave in air is $\approx 340 \text{ m/s}$, so 337 m/s is highly reasonable! Hertz has the unit s^{-1} , so $(\text{m/s}) / \text{Hz} = (\text{m/s}) \cdot \text{s} = \text{m}$, which is correct for wavelength.

Master Example 1: The “What-If” Scenario

The Twist: If the frequency were changed to **442 Hz**, what would be the new wavelength and period?

Note: Speed (v) remains 337 m/s because the medium hasn’t changed!



Insight: As frequency increases, wavelength and period strictly decrease.

Master Example 2: The Echo Challenge



The Trap: An echo represents a round trip. The sound travels to the cliff (465 m) and back (465 m).
Total distance $\Delta d = 2 \times 465 = 930 \text{ m}$.
Total time is 2.75 s.

a. Speed of Sound

$$v = \Delta d / \Delta t$$

$$v = 930 \text{ m} / 2.75 \text{ s}$$

$$v = 338 \text{ m/s}$$

b. Frequency (given $\lambda = 0.750 \text{ m}$)

$$f = v / \lambda$$

$$f = 338 / 0.750$$

$$f = 451 \text{ Hz}$$

c. Period

$$T = 1 / f$$

$$T = 1 / 451$$

$$T = 0.00222 \text{ s}$$

Comprehensive Practice Bank

[Speed]

Q1. A sound wave produced by a clock chime is heard 515 m away 1.50 s later. What is the speed of sound in air?

[Wavelength]

Q2. What is the speed of a periodic wave disturbance that has a frequency of 3.50 Hz and a wavelength of 0.700 m?

[Concept]

Q3. How does increasing the wavelength by 50 percent affect the frequency of a wave on a rope?

[Concept]

Q4. Describe the change in the wavelength of a wave when the period is reduced by one-half.

[Critical Thinking]

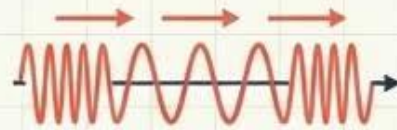
Q5. If a raindrop falls into a pool, it produces waves with small amplitudes. Why doesn't heavy rain in a thunderstorm produce giant waves?

The Ultimate Blueprint Summary

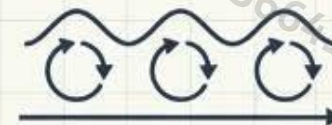
Taxonomy



Transverse
($\perp$ particle motion)



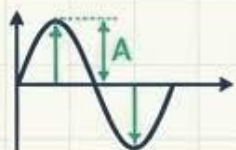
Longitudinal
($\parallel$ particle motion)



Surface
(Circular particle motion)

Rule: Medium dictates speed, not the source.

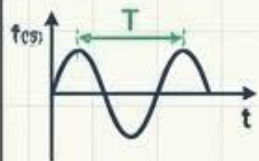
Anatomy & Time



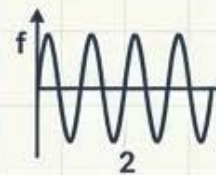
A = Amplitude
($E \propto A^2$)



λ = Wavelength
(Distance per cycle)



T = Period
(Time per cycle)



f = Frequency
(Cycles per second)

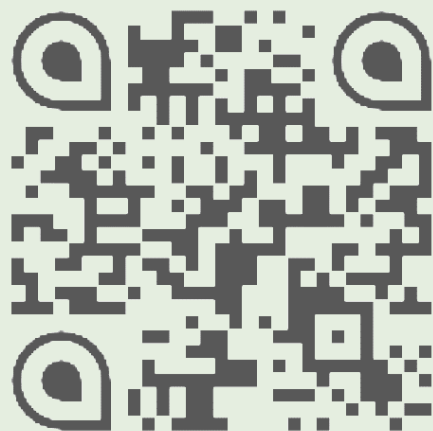
Core Equations

$$v = \frac{\Delta d}{\Delta t}$$

$$f = \frac{1}{T}$$

$$v = f \cdot \lambda$$

Final Review Prepared Exclusively by
Mr. Mohamad. Best of luck in your exams.



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Module (13): Vibrations and Waves

03

Third Lesson:
Wave Behavior



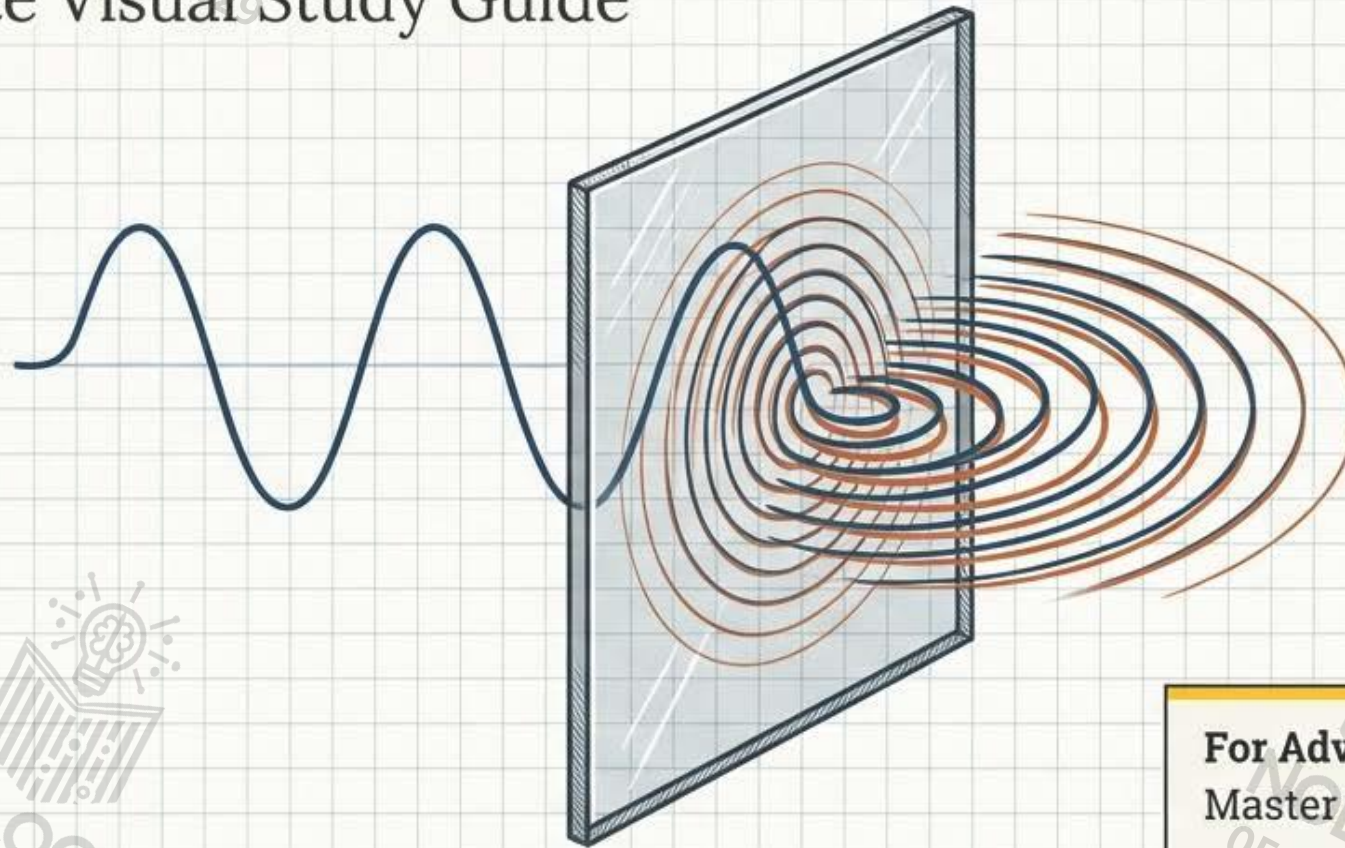
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Mastering Wave Dynamics: From 1D Pulses to Ocean Energy

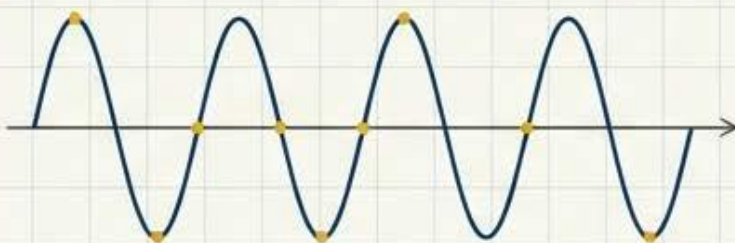
The Complete Visual Study Guide



For Advanced High School Physics
Master the Concepts, Ace the Exam.
Curated & Prepared by Mr. Mohamad

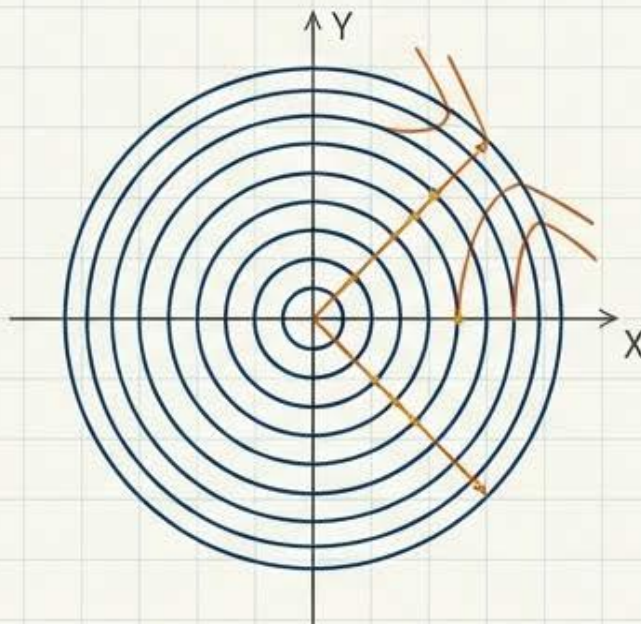
The Dimensional Escalation Framework

Step 1: 1D Systems (The Foundation)



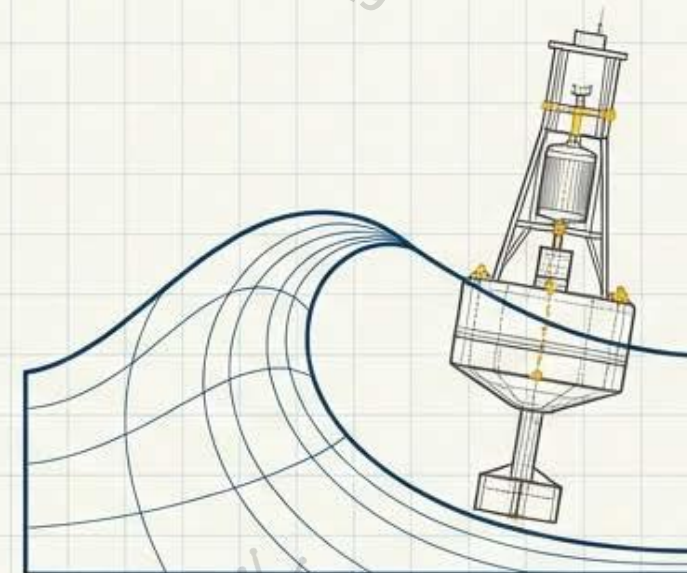
- Springs & Ropes
- Boundaries
- Superposition
- Standing Waves

Step 2: 2D Systems (The Surface)



- Ripple Tanks
- Wavefronts & Rays
- Reflection
- Refraction

Step 3: 3D Engineering (The Application)

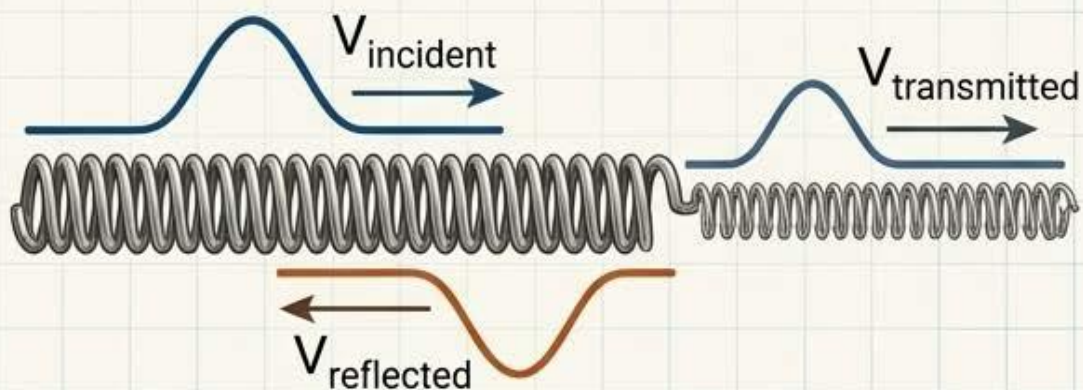


- Mechanical Resonance
- Energy Harvesting
- Ocean Wave Power

1D Wave Behavior: The Boundary Matrix

Flexible / Lighter Boundary

(Larger spring to smaller spring)



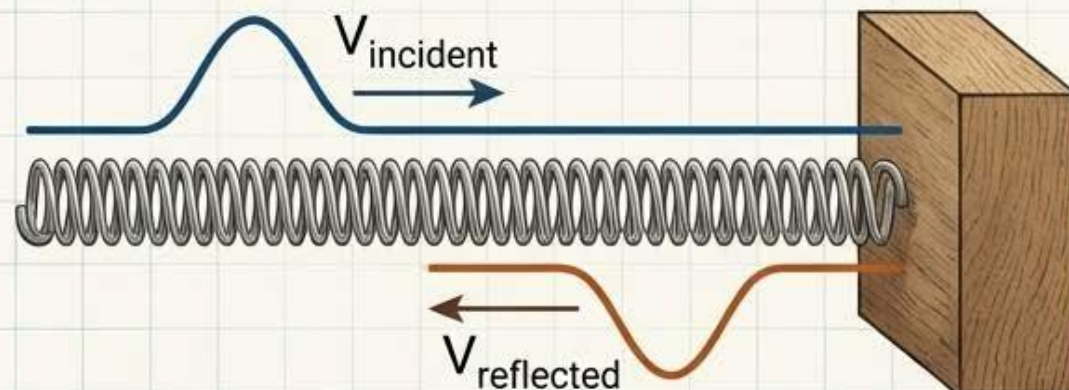
Reflected Phase: UPRIGHT

Speed Change: Transmitted wave changes speed based on tension/mass.

Energy: Split between transmitted and reflected pulses.

Rigid Boundary

(Spring attached to a solid wall)



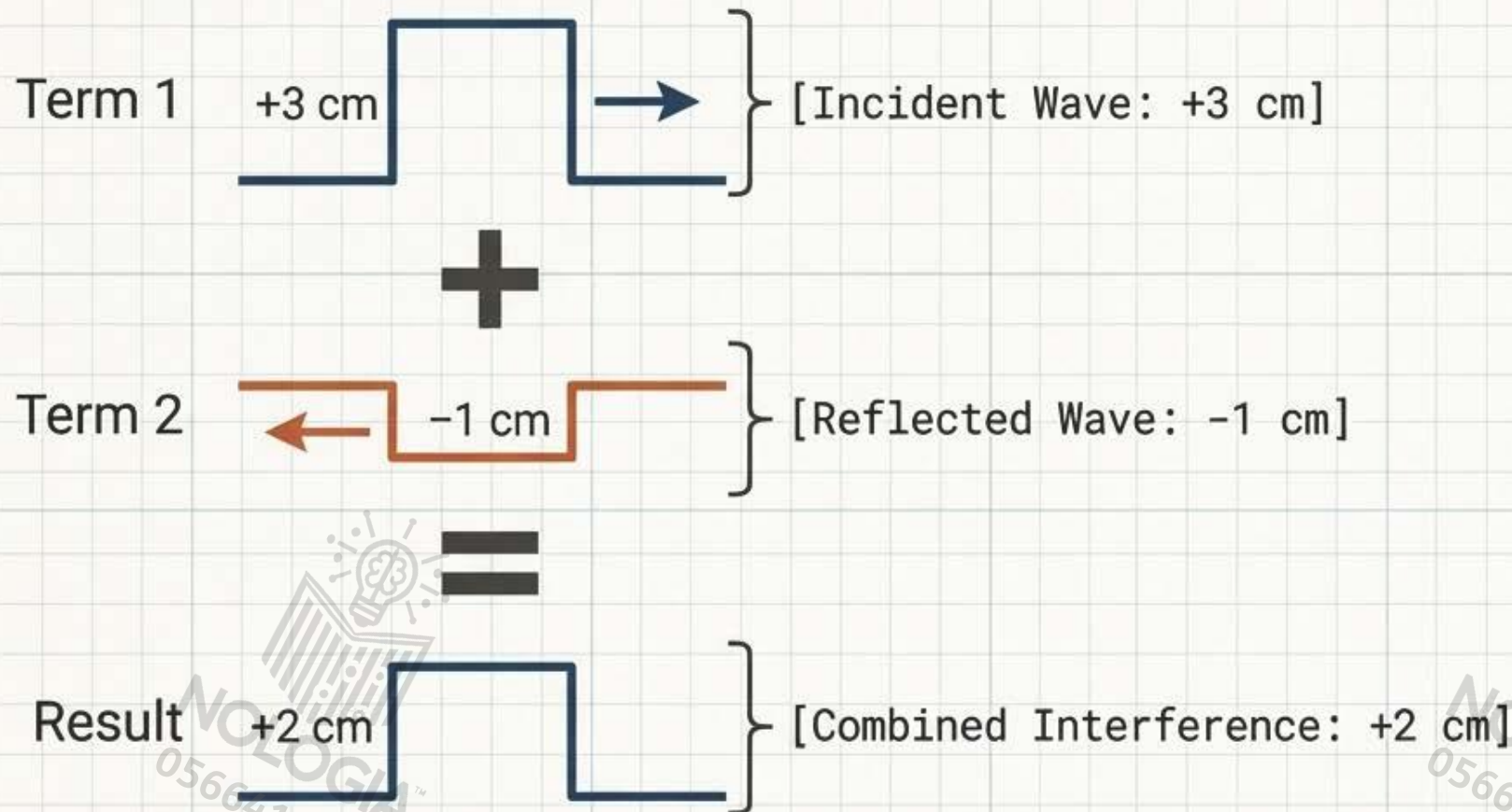
Reflected Phase: INVERTED

Speed Change: N/A (almost all energy reflects).

Energy: Almost 100% reflected back. Little to no transmission.

The Principle of Superposition

When two waves meet, their displacements add algebraically. They pass through each other completely unaffected.

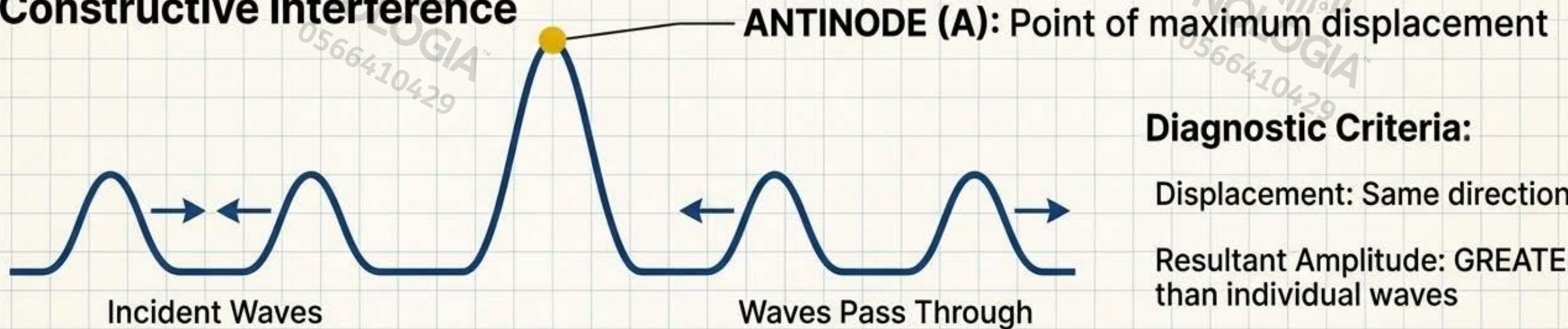


Crucial Rule:

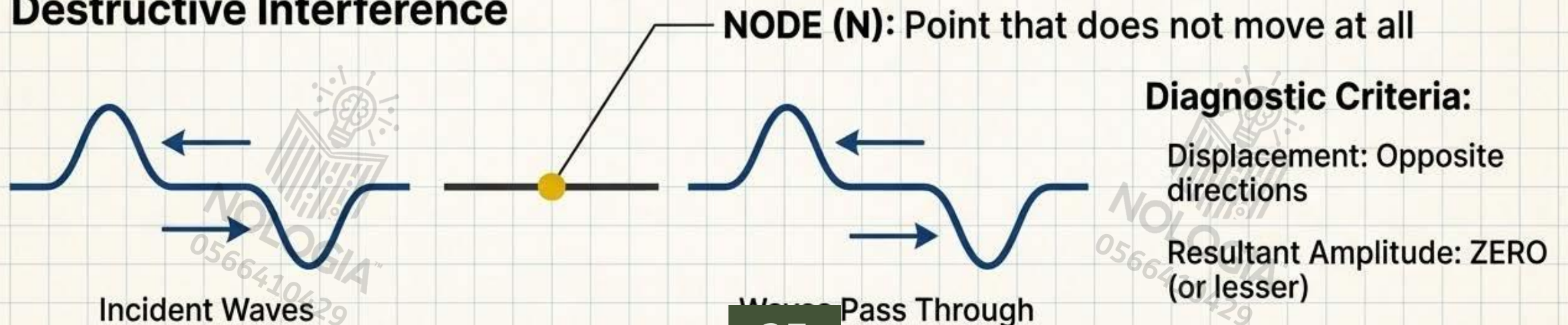
Waves affect the medium independently. They do not destroy each other. After crossing, they continue with their original shapes, speeds, and directions.

The Interference Diagnostic: Constructive vs. Destructive

Constructive Interference

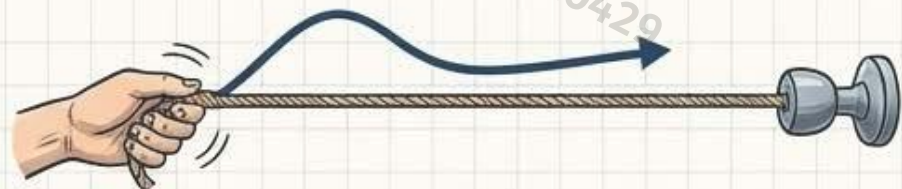


Destructive Interference

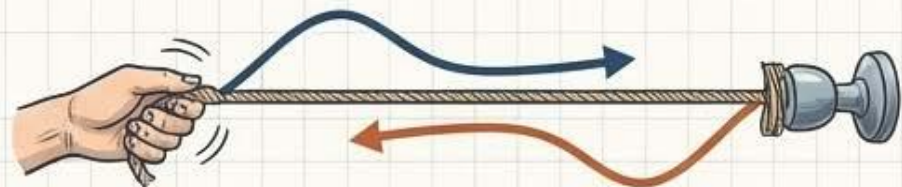


Anatomy of a Standing Wave (Mechanical Resonance)

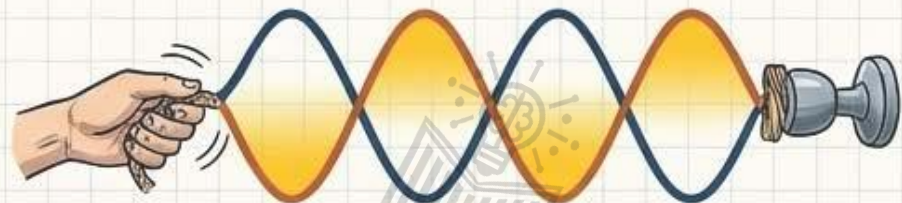
The Rope & Doorknob Analogy



1. **Generate** (Incident Wave goes out)



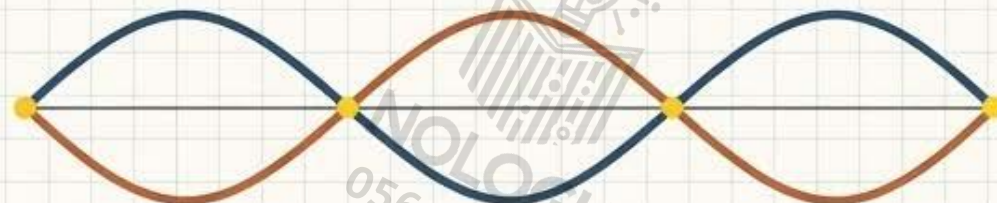
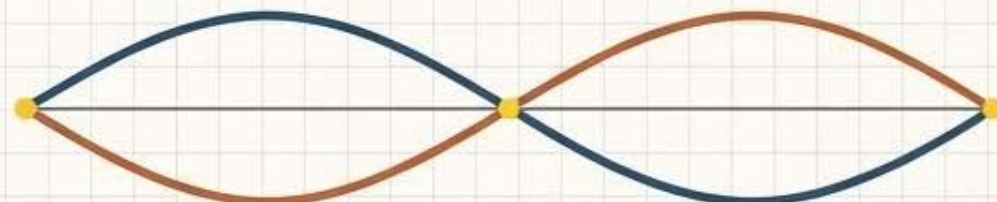
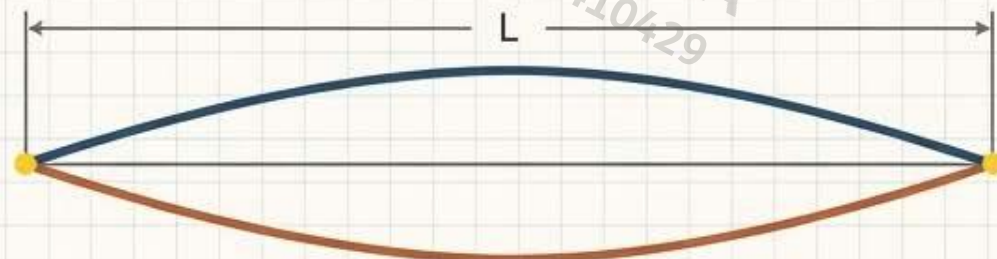
2. **Invert** (Hits rigid door, reflects inverted)



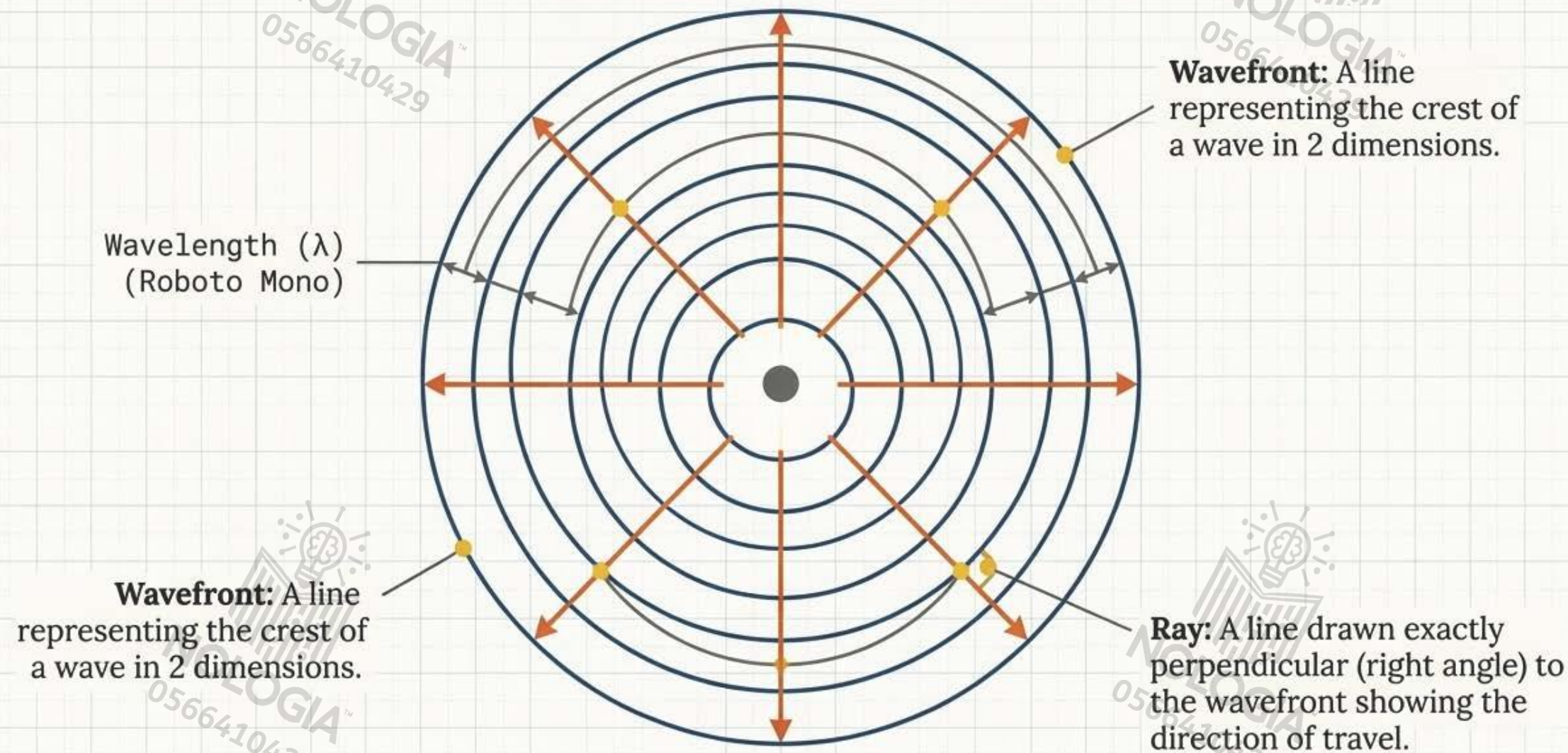
3. **Resonate** (Ongoing rhythm matches round-trip time, superimposing perfectly)

Standing Wave: The interference of waves traveling in opposite directions. The wave pattern appears perfectly still.

Standing Wave Frequencies



Stepping into 2D: Mapping Waves on a Surface



The Laboratory Apparatus: The Ripple Tank

Mechanical Oscillator:
Taps the water at a constant frequency to create straight, parallel wavefronts.

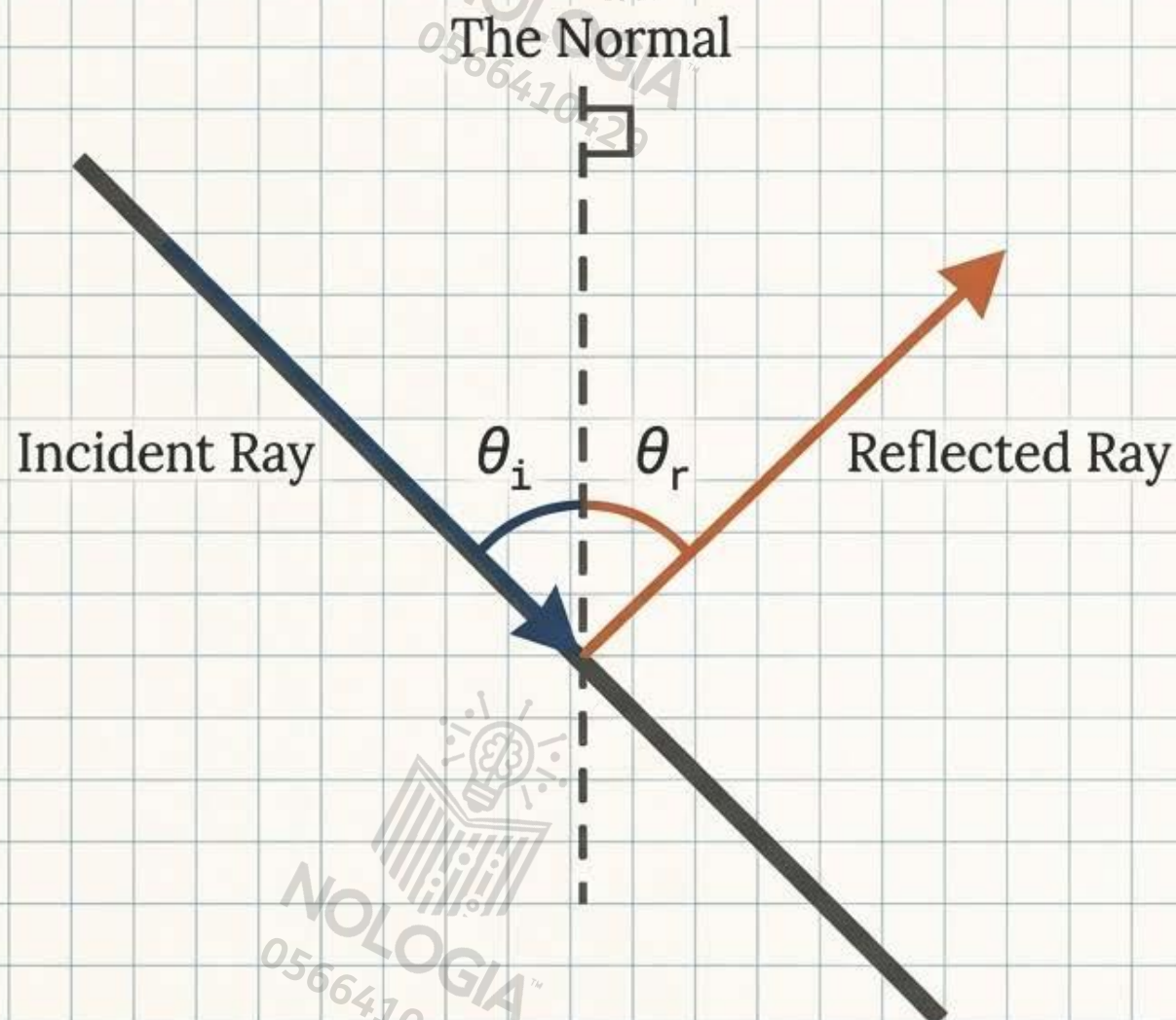
Lamp / Illumination:
Shines down through the water, casting shadows.

Shallow Tank of Water:
The 2D medium.

Viewing Screen:
Displays the alternating bright and dark lines caused by the water crests acting as lenses.

How it works: Light passes through crests → Casts shadows on screen → Allows real-time mapping of wave speed, reflection, and refraction.

2D Reflection: Bouncing Off Boundaries



The Golden Rule:

The Law of Reflection

$$\theta_i = \theta_r$$

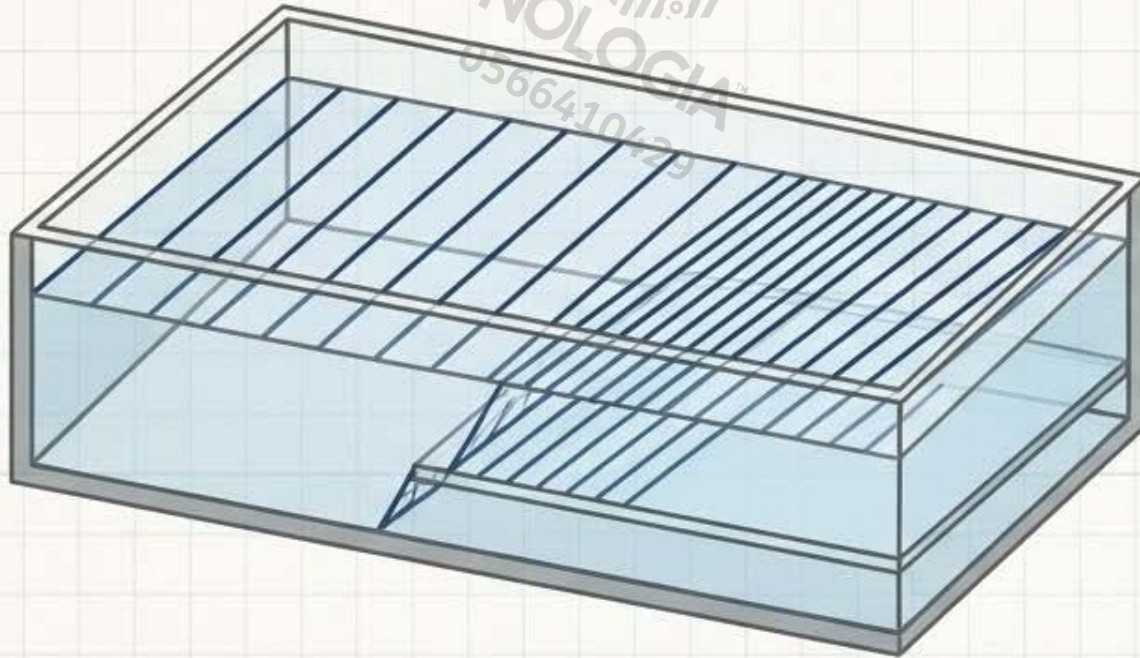
(Always measured from the Normal line, never the barrier surface!)



Real-World Proofs:

- **Acoustics:** Echoes bouncing perfectly off the hard walls of a gymnasium.
- **Optics:** Light reflecting seamlessly off a smooth bathroom mirror.

2D Refraction: The Medium Shift Matrix



Ripple tank showing wavefronts undergoing refraction as they pass from deep to shallow water.

Medium Changes (Depth) →
 ↳ Speed Decreases →
 ↳ Wavelength Shortens →
 ↳ Direction Shifts (Refraction)

1	2
Deep Water	Shallow Water
• Greater Speed (v) • Longer Wavelength (λ) • Wider wavefront spacing	• Lower Speed (v) • Shorter Wavelength (λ) • Tighter wavefront spacing



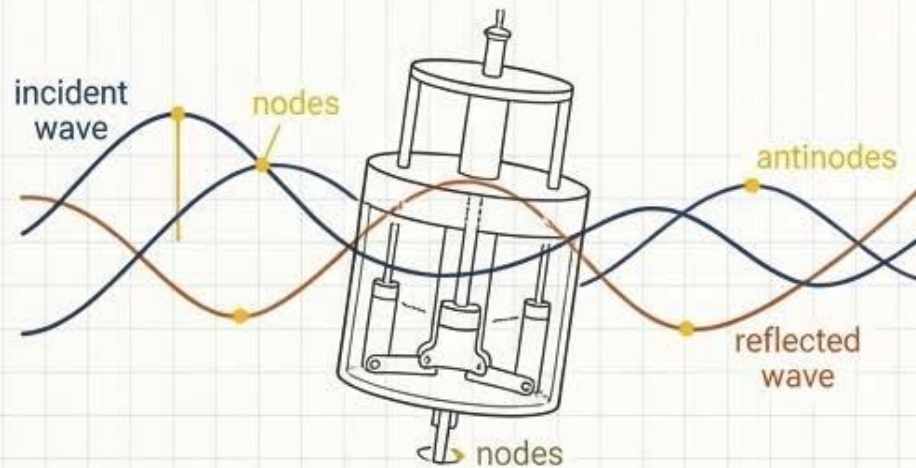
EXAM TRAP: CONSTANT VARIABLE

Frequency (f) NEVER changes when a wave enters a new medium! The wave in the shallow water is physically connected to the wave in the deep water.

Engineering Synthesis: Harnessing Ocean Motion

How engineers apply 1D boundary laws and 2D superposition to capture massive, untapped mechanical energy.

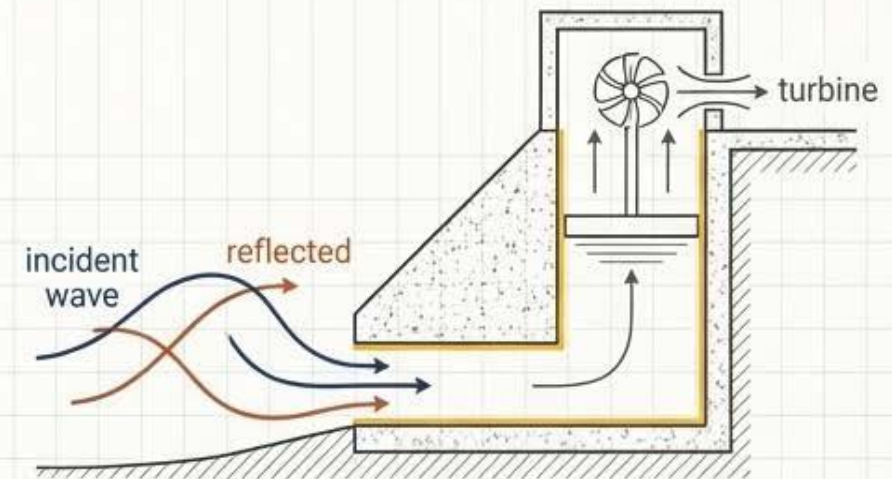
Design 1: Point Absorber (Floating Buoy)



Concept Link: Amplitude & Superposition

As 2D ocean waves rise and fall, the buoy's parts move relative to each other, driving a hydraulic pump to generate electricity.

Design 2: Oscillating Water Column (Terminator)



Concept Link: Rigid Boundaries

Placed onshore, ocean waves push water into a rigid column. The water forces trapped air up and down through a turbine.

The Ultimate Challenge: Engineers must design devices that capture maximum wave amplitude (energy) while acting as durable rigid boundaries against corrosive saltwater and violent storms.



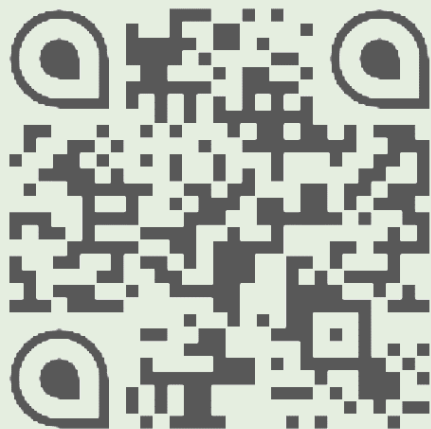
Module (14): Sound

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Module (14): Sound

01

First Lesson:
Properties and Detection
of Sound



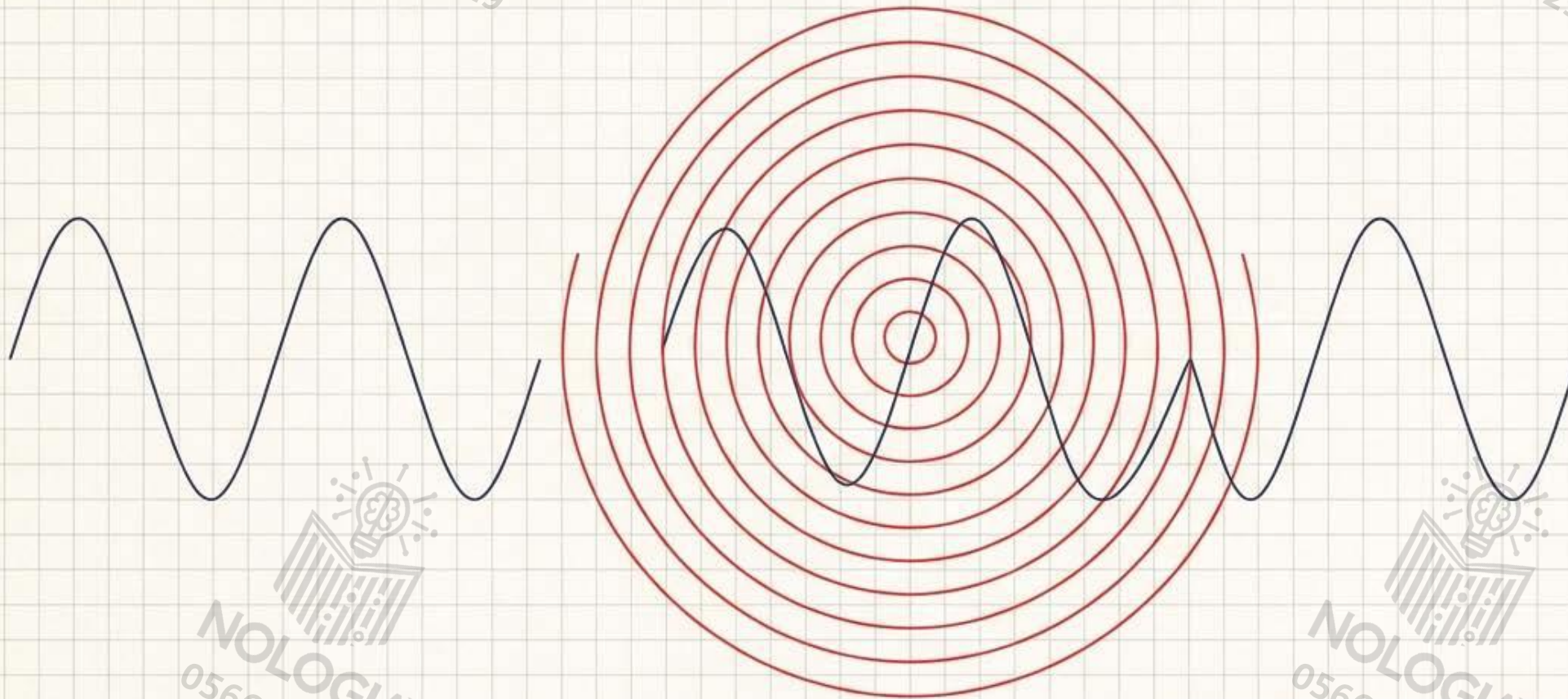
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THE ARCHITECTURE OF SOUND

A COMPLETE STUDY GUIDE TO PROPERTIES, PERCEPTION, AND THE DOPPLER EFFECT



MR. MOHAMAD'S PHYSICS MASTERCLASS

Properties & Detection of Sound

Phase 1: Creation

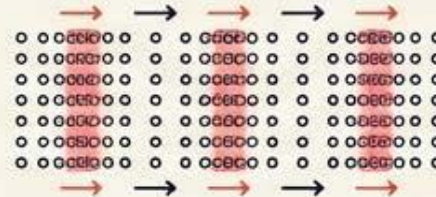
The Source



Vibrating objects create regular pressure variations (oscillations) in a medium.

Phase 2: Transmission

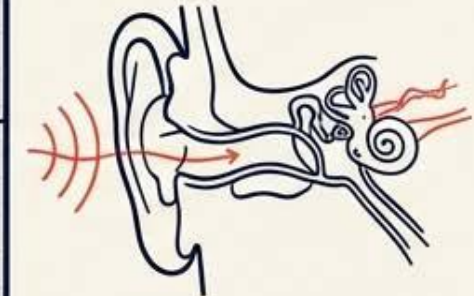
The Medium



Longitudinal waves travel through particle collisions. Speed depends entirely on the material.

Phase 3: Detection

The Observer



Translating kinetic energy into electrical signals (the human ear) or mechanical data (microphones).

Fundamental Rule: Sound is a longitudinal wave.
Particle motion is strictly parallel to the direction of the wave's travel.

The Translation Map: Four Views of One Wave

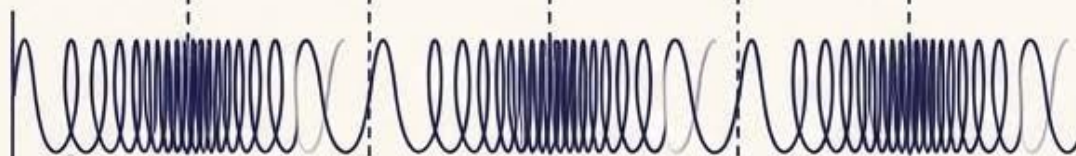
1. Vibrating Bell



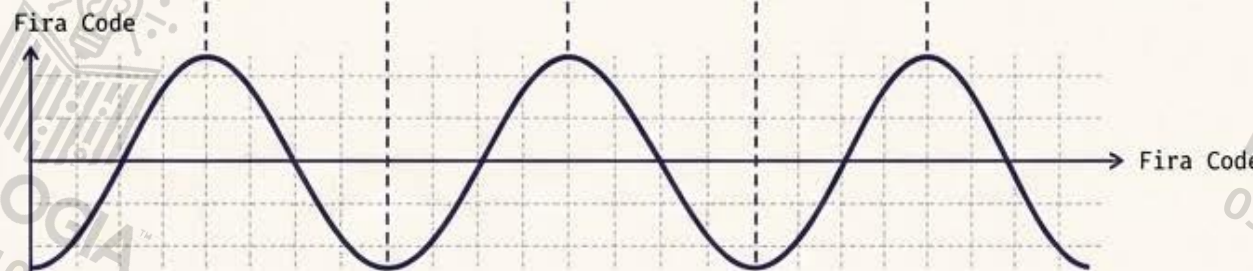
2. Air Pressure Changes



3. Coiled Spring Model



4. Sine Curve Graph



The Blueprint of a Sound Wave

Every physical property maps perfectly to mathematics.

- High Pressure = Compressed Coils = Wave Crests
- Low Pressure = Stretched Coils = Wave Troughs

Wavelength (λ) is the physical distance between two successive regions of high or low pressure.

The Velocity Variable: Speed of Sound

Core Principle

Sound waves rely on particle collisions to travel. Therefore, sound absolutely cannot travel in a vacuum.

Formula Anatomy

Air Speed Baseline:
At room temperature
(20°C) and sea level.

$$v = 343 \text{ m/s}$$

The Temperature Variable



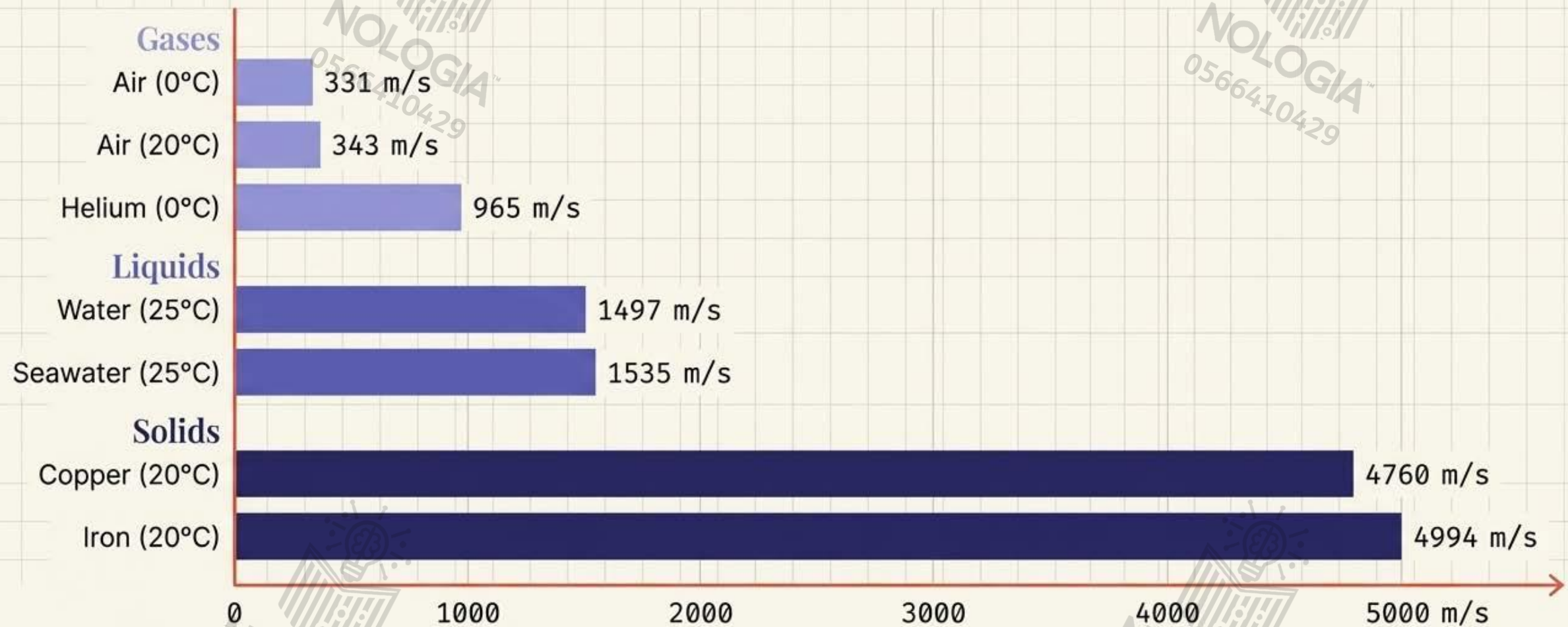
In air, speed increases by roughly 0.6 m/s for each 1°C increase in temperature.

Real-World Application: Echoes

Echoes occur when sound waves reflect off hard objects. The time required for an echo to return allows us to calculate exact distances.

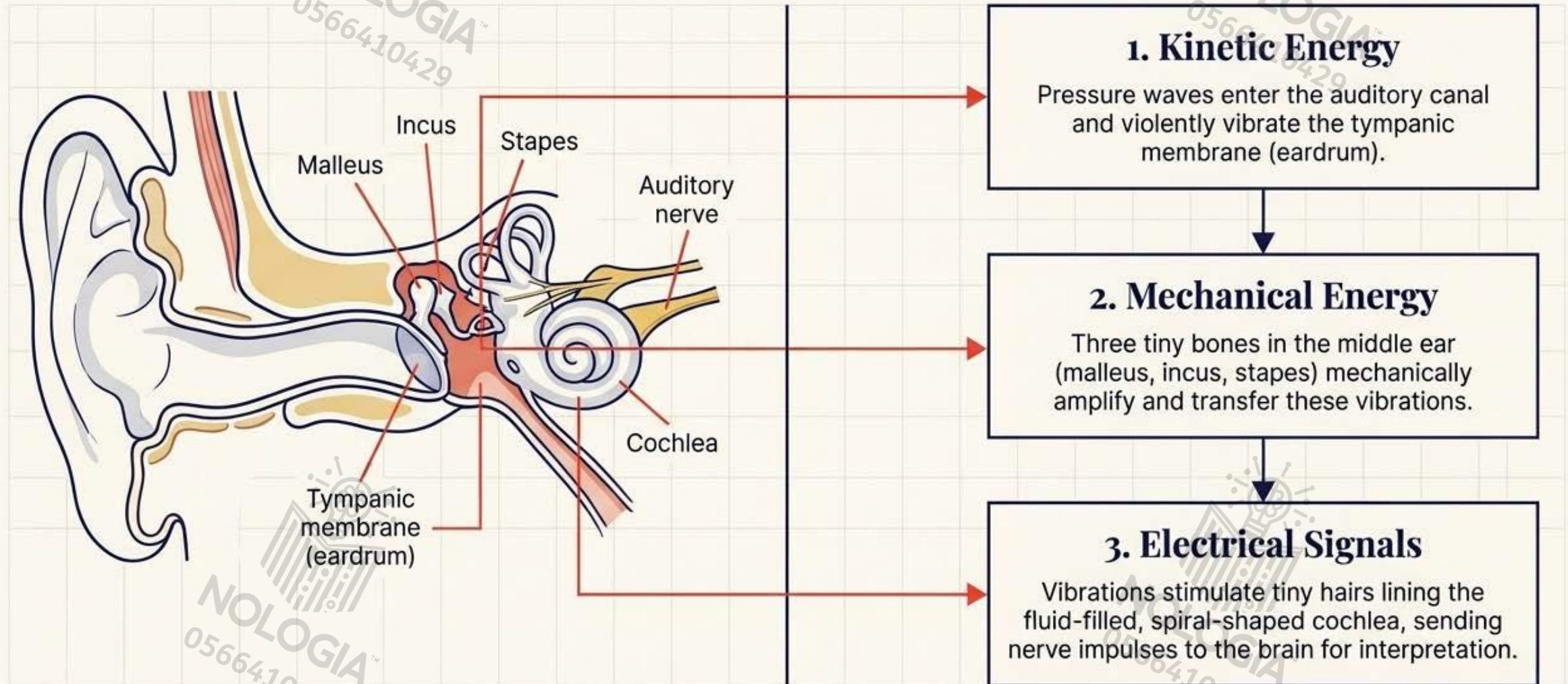


Speed of Sound Across Different Media



Why do solids win? Proximity. Particles in iron are packed tightly together, allowing vibrations to transfer almost instantly compared to the sparse gas particles in the air.

The Human Ear as an Energy Transducer

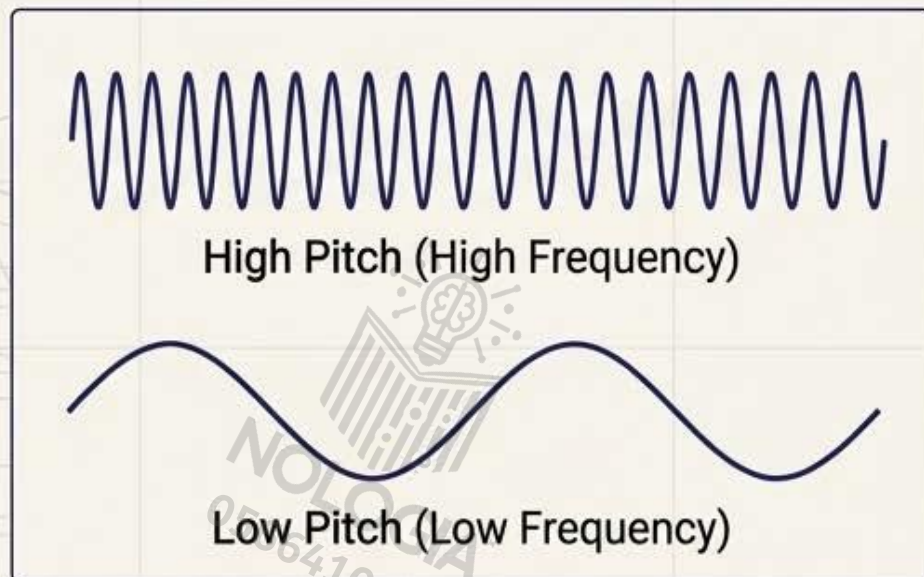


Diagnostic Matrix: Pitch vs. Loudness

PITCH

Driven by: Frequency

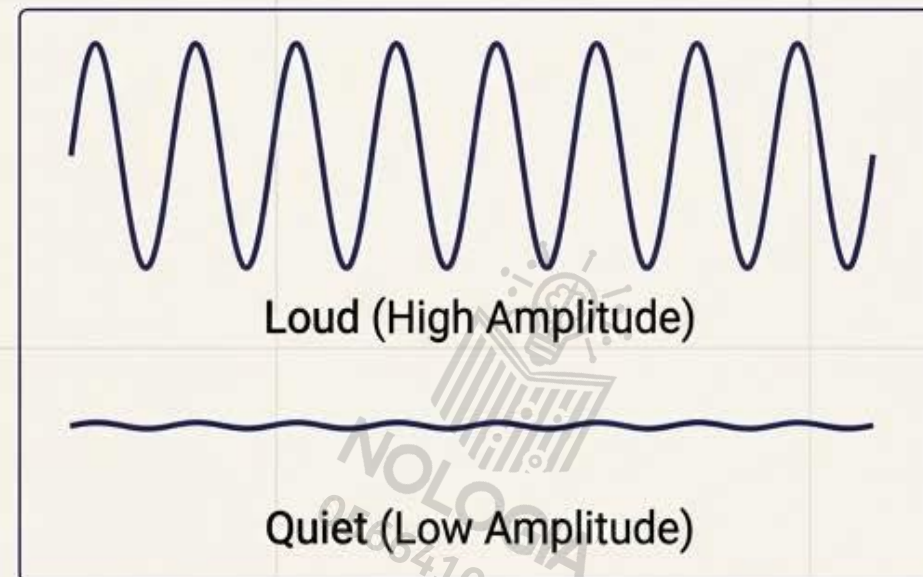
Human Range: 20 Hz to 16,000 Hz. (Dogs and bats hear much higher).



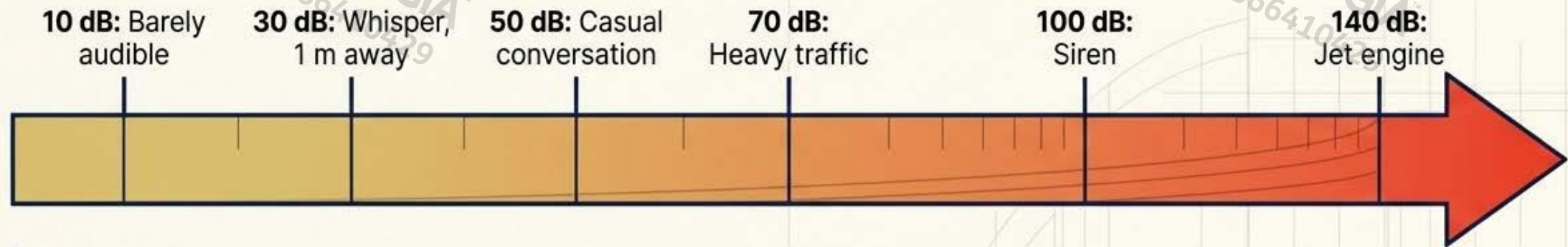
LOUDNESS

Driven by: Amplitude (Intensity of pressure variation)

Human Range: Threshold of hearing is 2×10^{-5} Pa. Variations above 20 Pa cause pain.



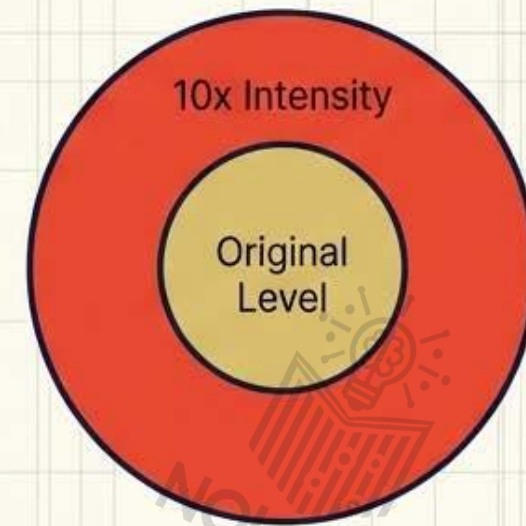
Decibels (dB): Measuring Sound Level



The Logarithmic Rule

Sound level is based on the ratio of intensity to the faintest heard sound (0 dB).

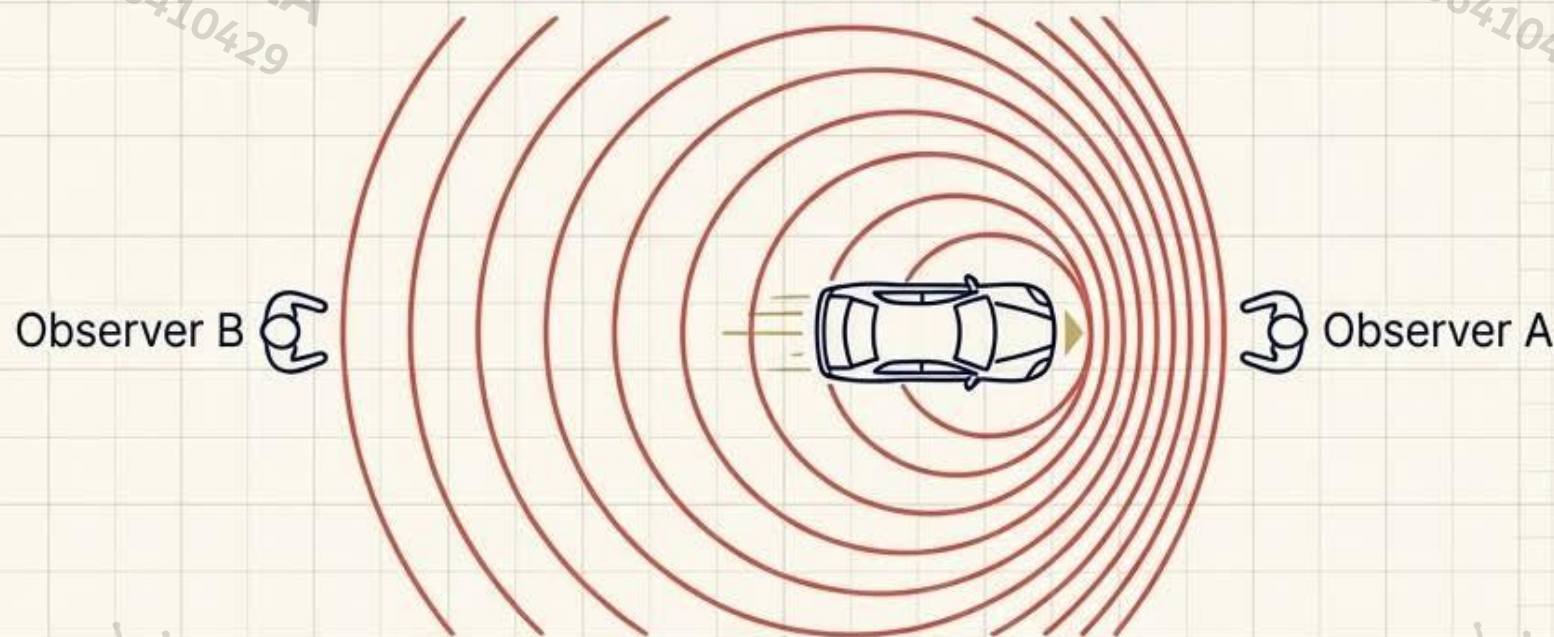
A sound 10 times more intense registers +10 dB.
A sound 100 times more intense registers +20 dB.



Perception Note: Most people perceive a 10-dB increase as being twice as loud.

The Doppler Effect in Action

The change in frequency of sound caused by the movement of either the source, the detector, or both.



Observer A (Front)

- Source moves toward the detector.
- Wavefronts are crowded together.
- Wavelength (λ) shortens.
- Result: Detected frequency (pitch) increases.

Observer B (Behind)

- Source moves away.
- Wavefronts are spread out.
- Wavelength (λ) lengthens.
- Result: Detected frequency (pitch) decreases.

Formula Anatomy: The Doppler Effect

$$f_d = f_s * \left(\frac{v - v_d}{v - v_s} \right)$$

Diagram illustrating the components of the Doppler Effect formula:

- f_d : Frequency perceived by detector (Hz)
- f_s : Frequency of the source's wave (Hz)
- v : Velocity of the sound wave itself (e.g., 343 m/s in air)
- v_d : Velocity of the detector
- v_s : Velocity of the source

CRITICAL: The Coordinate System Rule

Always define the positive direction as pointing FROM the source TO the detector. The sound waves **will be approaching** the detector from the source, so the **velocity of sound (v) is always positive**.

Reducing the Doppler Equation

When an element in the equation is equal to zero, drop it to form a significantly easier equation.

Stationary detector, source in motion: $v_d = 0$

$$f_d = f_s * \left(\frac{v - v_d}{v - v_s} \right)$$

$$f_d = f_s * \left(\frac{v}{v - v_s} \right)$$

$$f_d = f_s * \frac{1}{1 - (v_s / v)}$$

Stationary source, detector in motion: $v_s = 0$

$$f_d = f_s * \left(\frac{v - v_d}{v - v_s} \right)$$

$$f_d = f_s * \left(\frac{v - v_d}{v} \right)$$

$$f_d = f_s * \left(1 - \frac{v_d}{v} \right)$$

Step-by-Step Problem Solving

Problem

A convertible moving at 24.6 m/s plays a 523 Hz note. What frequency does a stationary observer ahead hear? (Assume air temp is 20°C).



Step 1: Analyze & Identify Variables

- Velocity of sound (v) = +343 m/s
- Velocity of source (v_s) = +24.6 m/s (moving toward detector)
- Velocity of detector (v_d) = 0 m/s
- Frequency of source (f_s) = 523 Hz

Step 2: Solve for Unknown (f_d)

Use the reduced formula for a stationary detector: $f_d = f_s * \frac{1}{1-(v_s/v)}$

Substitute values:

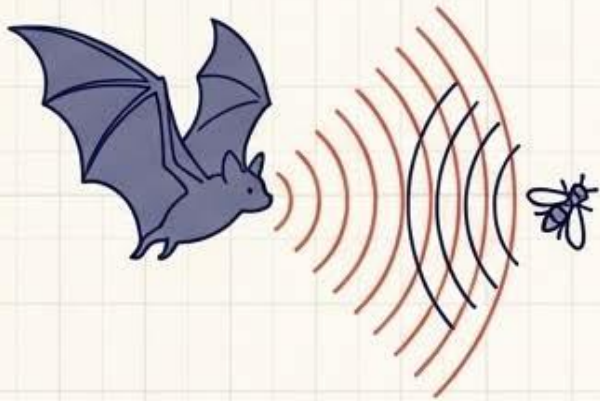
$$f_d = 523 \text{ Hz} * \frac{1}{1-(24.6/343)}$$
$$f_d = 564 \text{ Hz}$$

Step 3: Evaluate the Answer

Is the magnitude realistic? The source is moving toward the observer, so the frequency should be increased. It increased from 523 Hz to 564 Hz. The logic holds.

The Doppler Effect in the Real World

Biology: Echolocation



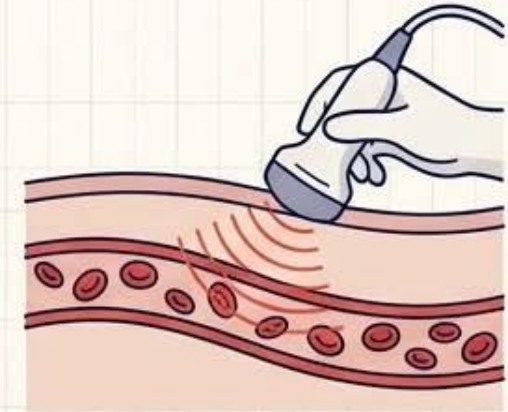
Bats emit sound waves to locate prey. If an insect is flying away, the reflected frequency is lower. As the bat catches up to the insect, the reflected frequency shifts higher, allowing precise targeting.

Technology: Radar & Speed



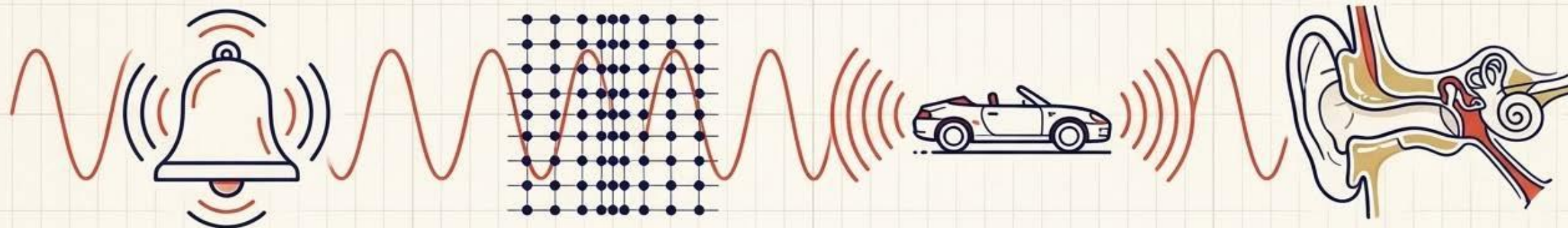
Police radar detectors bounce electromagnetic waves off moving cars. By measuring the exact frequency shift of the returning wave, the device instantaneously calculates the vehicle's speed.

Medicine: Ultrasounds



Physicians harness the Doppler effect in ultrasound technology to accurately measure the velocity of blood flow or monitor the rapidly changing heartbeat of a fetus.

Synthesis: The Master Blueprint of Sound



1. The Source

Dictates the base Frequency (Pitch) and Amplitude (Loudness).

2. The Medium

Dictates the Velocity (343 m/s in air, significantly faster in solids).

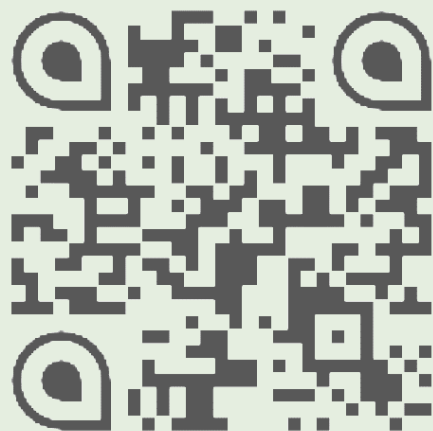
3. Relative Motion

Dictates the Doppler Shift (physically compressing or stretching the wave).

4. The Detector

Translates the final physical pressure wave into perceived decibels and tone.

Conclusion: By isolating these four physical variables, we can mathematically calculate, predict, and manipulate the behavior of sound in any environment.



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Module (14): Sound

02

Second Lesson:
The Physics of Music



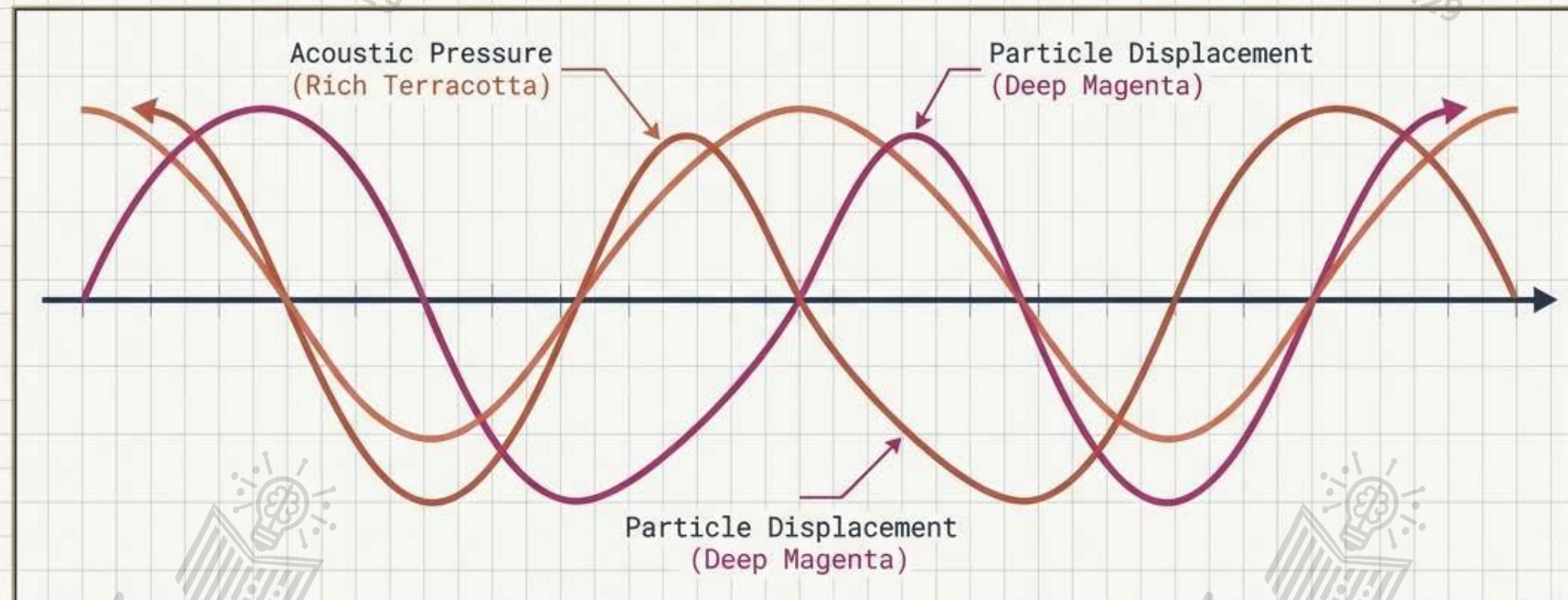
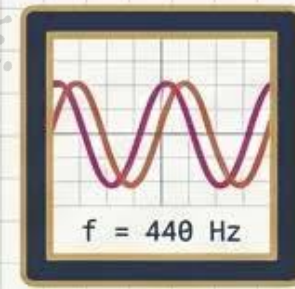
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The Physics of Music: Resonance, Waves, and Pitch

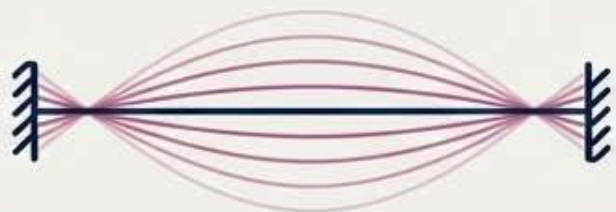
A Comprehensive Master Guide to Acoustic Physics



Curated & Designed by
Mr. Mohamad

The Origin of Sound: From Vibration to Wave

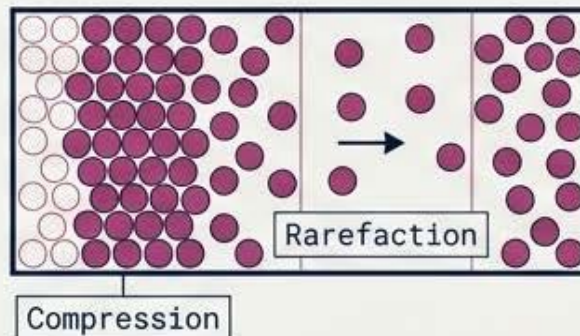
Step 1: The Source



Vibrating Object

The origin point of all acoustic energy.

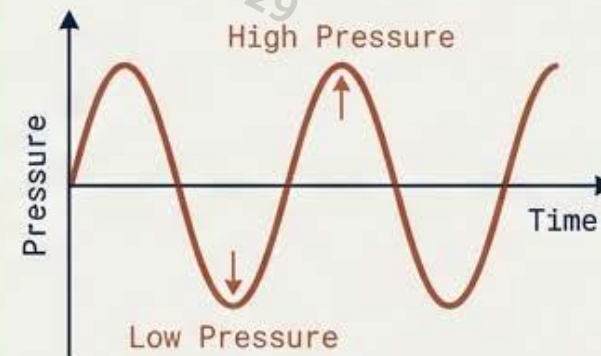
Step 2: The Medium



Particle Motion

Vibrations force air molecules to collide, creating alternating regions of density.

Step 3: The Wave



Pressure Oscillations

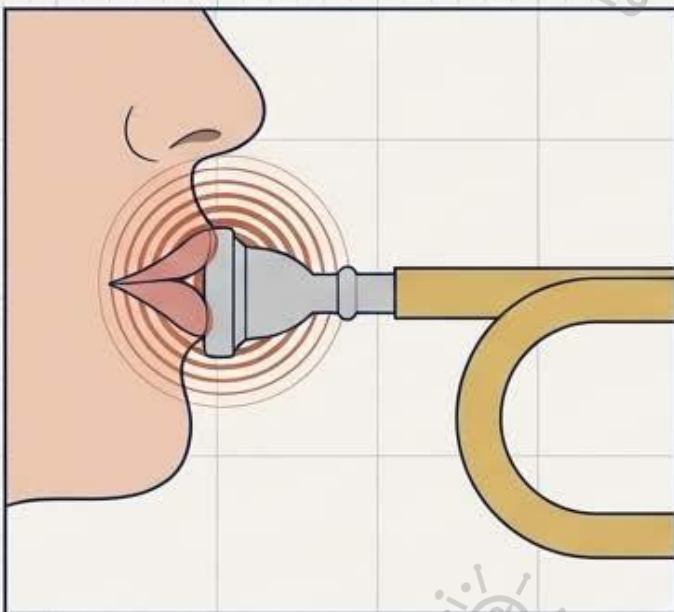
These particle collisions travel as continuous waves of high and low pressure.

Focus Question: How is pitch controlled?

By altering the frequency of the source vibration.

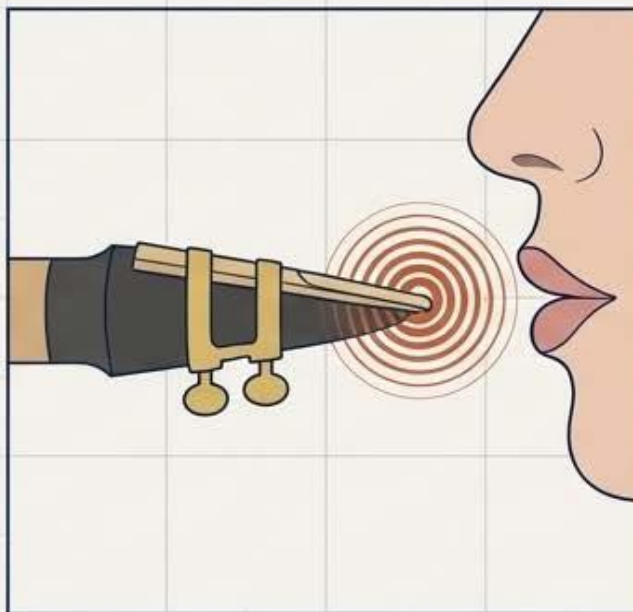
Anatomy of Acoustic Vibration

Brass Instruments



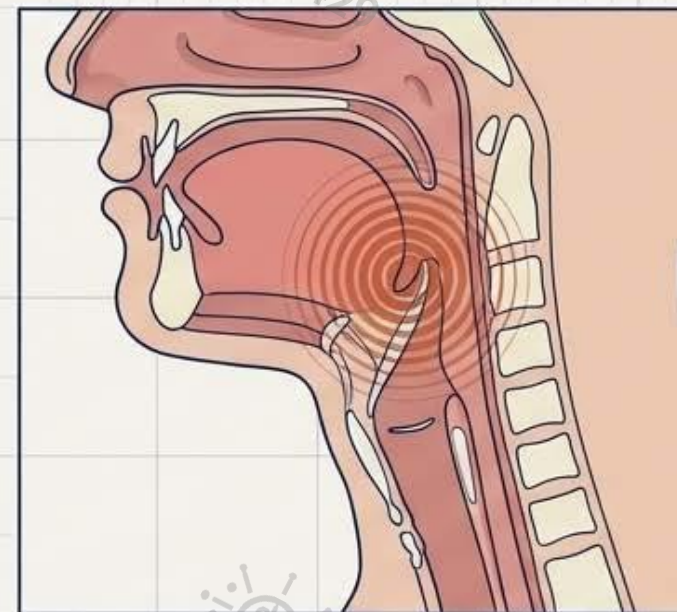
The performer's lips vibrate against the metal rim to initiate the wave.

Woodwind Instruments



A thin wooden strip (reed) vibrates rapidly as air is blown across it.

The Human Voice



Two membranes in the throat vibrate. Pitch is controlled directly by muscular tension (tighter = faster vibration = higher pitch).

Note: Flutes and organ pipes rely on air forced across an opening, while strings rely on wire friction or striking, which is then amplified by a sounding board.

Resonance: Turning Noise into Music

1

The Source:

Tuning fork creates a specific, constant vibration frequency.



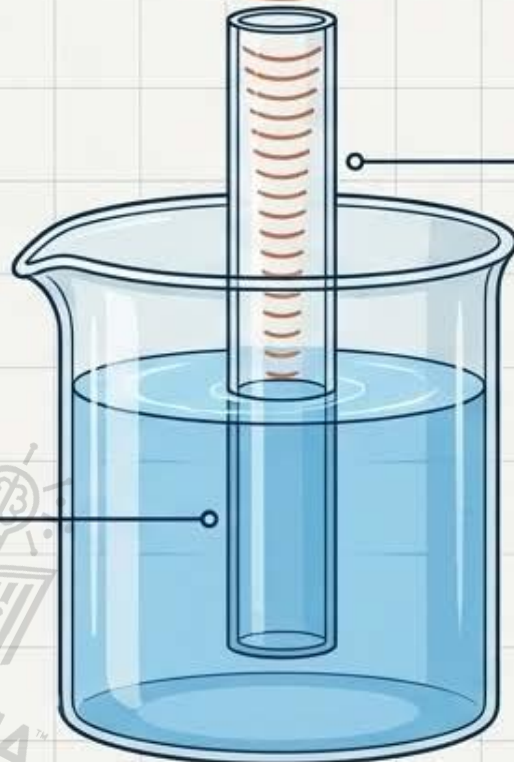
3

The Phenomenon:

Resonance occurs when the air column's natural frequency perfectly matches the tuning fork.

2

The Column: Air column length is adjusted by raising or lowering the tube in the water.

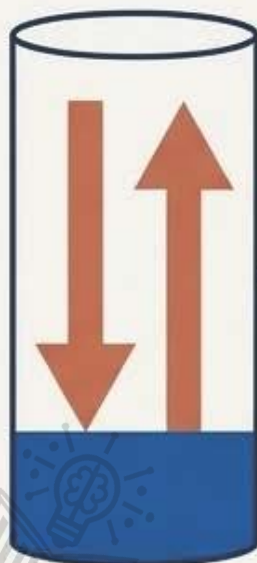


Key Insight

Resonance amplifies vibration. The mouthpiece creates a chaotic mixture of frequencies. The specific length of the instrument's air column acts on a specific set of frequencies to amplify a single note.

The Reflection Cycle: Boundary Conditions

Closed Pipe (Water boundary)



Sound reflects
off a closed end.

Water Boundary

High-pressure wave reflects as a
High-pressure wave.

Open Pipe (Air boundary)

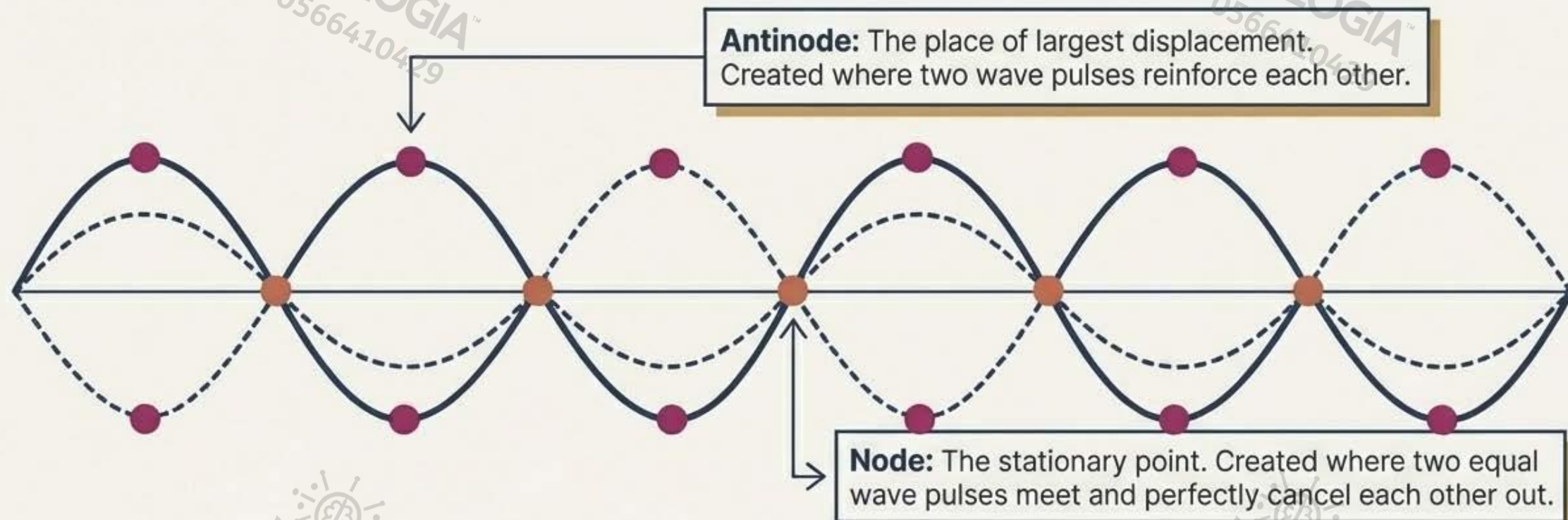


Sound reflects
off an open end.

Open End

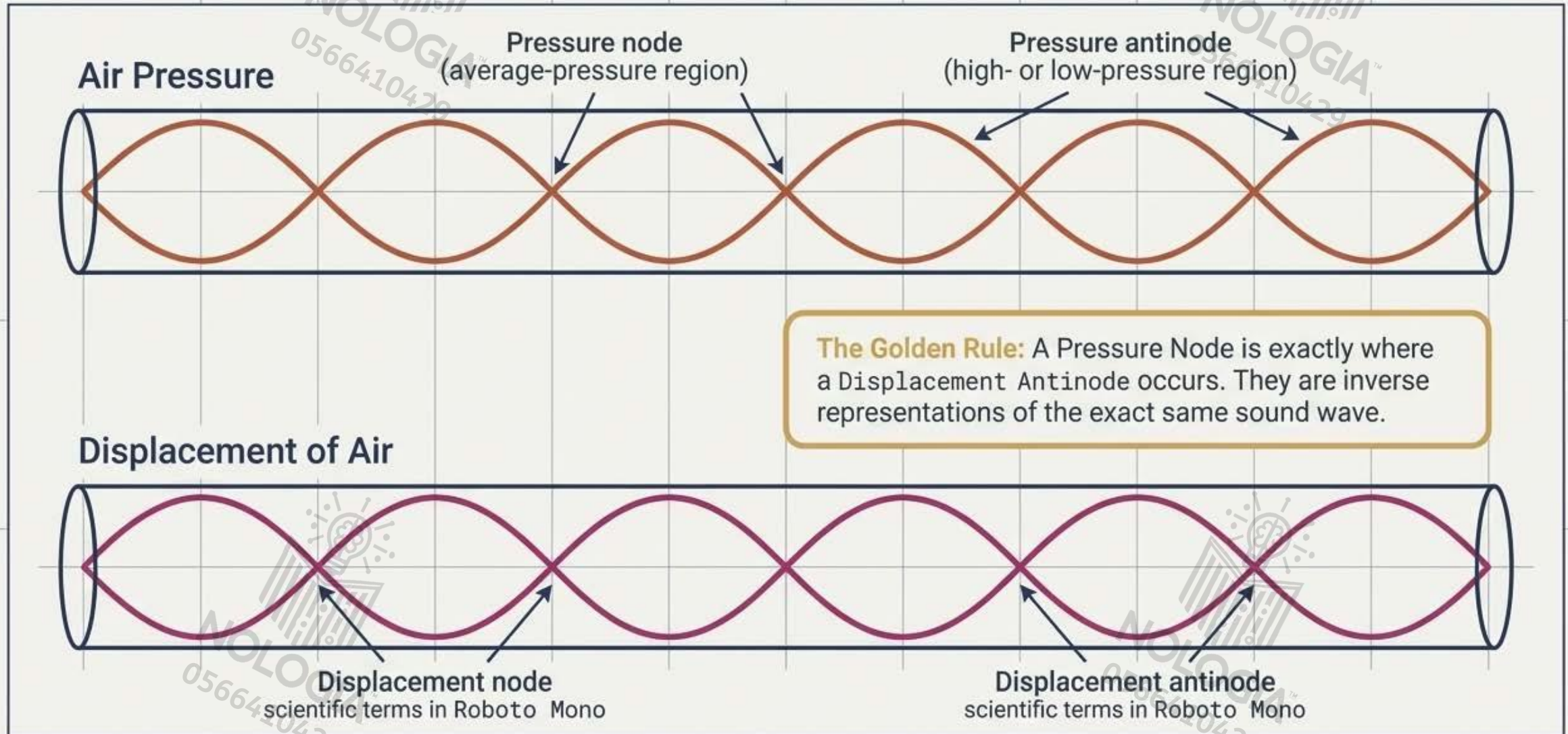
High-pressure part of the wave
reflects as a Low-pressure wave.

Anatomy of a Standing Wave



Fundamental Rule: Distance between two adjacent antinodes (or two adjacent nodes) is exactly one-half wavelength ($\lambda/2$).

The Dual Nature of Acoustic Waves



Closed-Pipe Resonators: The Fundamental

Physical Constraints

- Closed End = Displacement Node (air cannot move against the barrier).
- Open End = Displacement Antinode (air moves freely into the atmosphere).



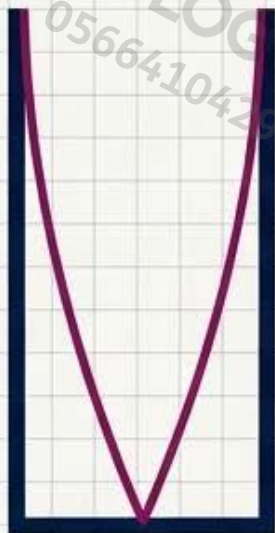
Shortest column to fit these conditions is one-fourth of a wavelength.

$$L = \frac{\lambda_1}{4} \rightarrow \lambda_1 = 4L$$

$$f_1 = \frac{v}{\lambda_1} = \frac{v}{4L}$$

End Correction Note: In practice, the node is ~0.4 pipe diameters beyond the open end. The spacing between resonances can be used to experimentally find the velocity of sound in air.

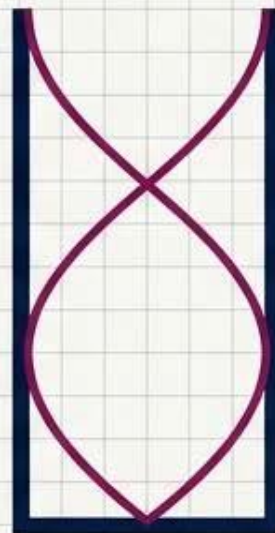
Closed Pipes: The Odd Harmonics Rule



Fundamental (1st Harmonic)

$$\lambda_1 = 4L$$

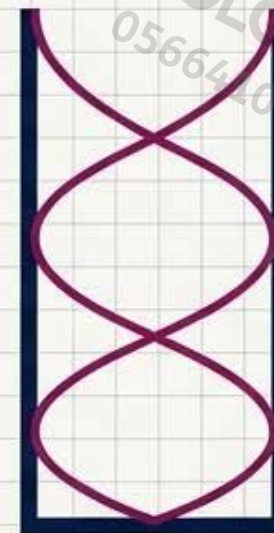
$$f_1 = v / 4L$$



3rd Harmonic

$$\lambda_3 = 4L / 3$$

$$f_3 = 3v / 4L = 3f_1$$



5th Harmonic

$$\lambda_5 = 4L / 5$$

$$f_5 = 5v / 4L = 5f_1$$

Key Takeaway: Because a closed pipe **MUST** have a node at one end and an antinode at the other, it can only resonate at odd quarter-wavelength intervals. **Even harmonics** ($2f_1$, $4f_1$) are physically impossible.

Open-Pipe Resonators: The Fundamental

Physical Constraints

- Open End 1 = Displacement Antinode.
- Open End 2 = Displacement Antinode.

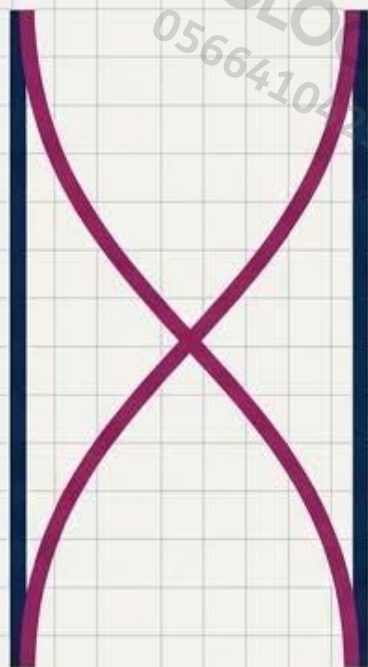


Shortest column to have antinodes at both ends is **one-half** of a wavelength.

$$L = \frac{\lambda_1}{2} \rightarrow \lambda_1 = 2L$$

$$f_1 = \frac{v}{\lambda_1} = \frac{v}{2L}$$

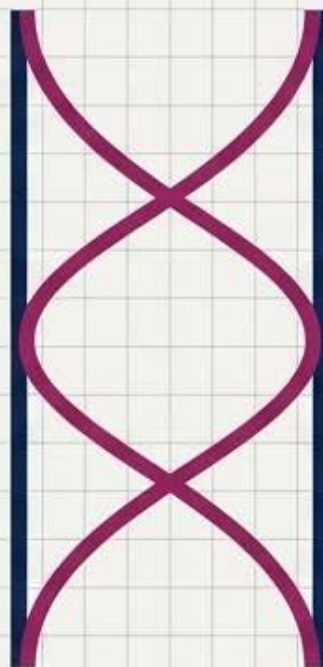
Open Pipes: All Harmonics Allowed



Fundamental (1st Harmonic)

$$\lambda_1 = 2L$$

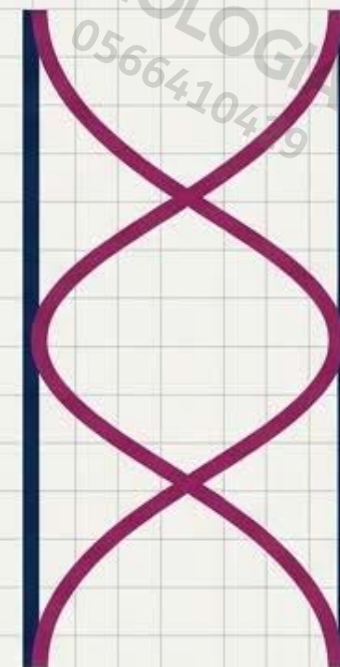
$$f_1 = v / 2L$$



2nd Harmonic

$$\lambda_2 = L$$

$$f_2 = v / L = 2f_1$$



3rd Harmonic

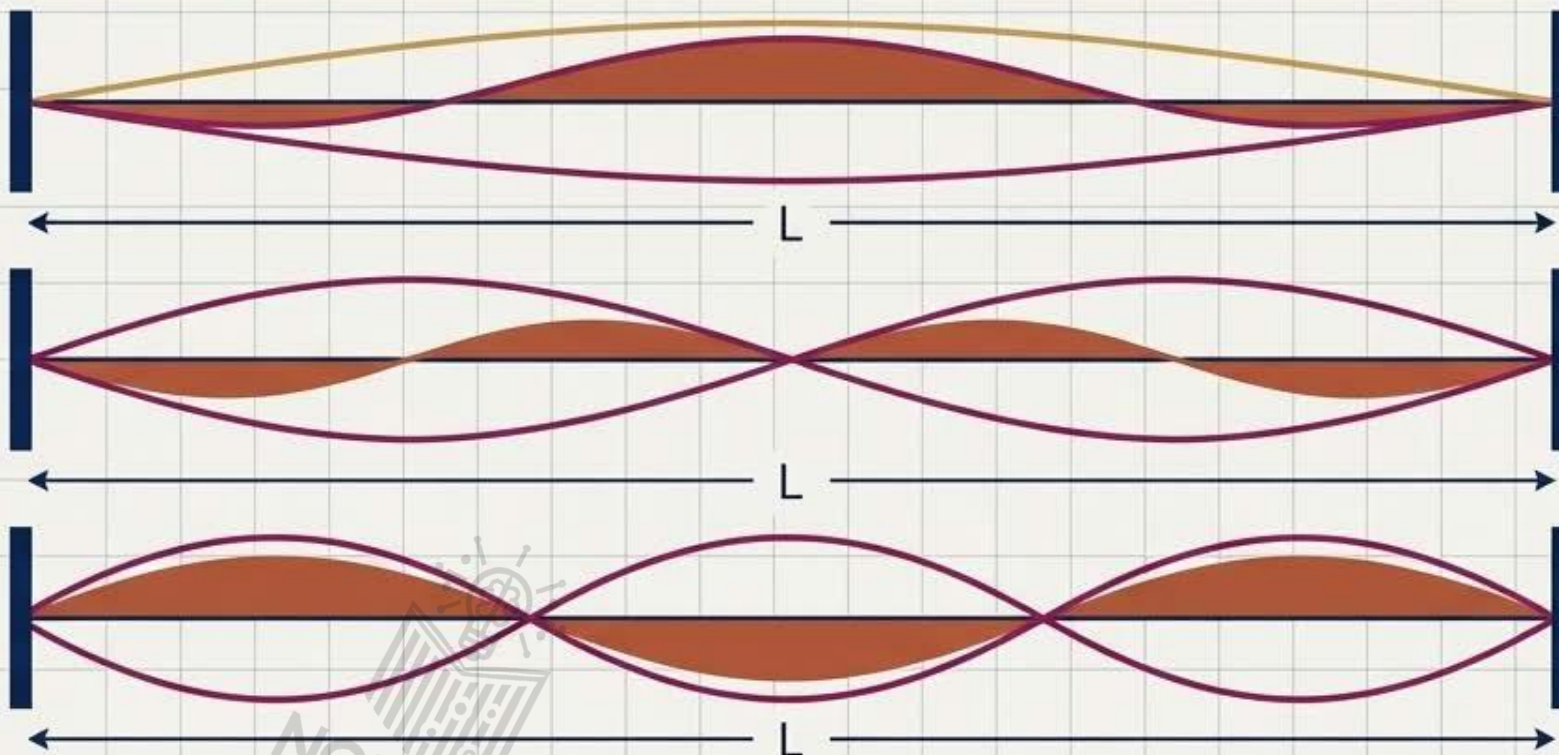
$$\lambda_3 = 2L / 3$$

$$f_3 = 3v / 2L = 3f_1$$

Key Takeaway: Because boundary conditions are identical at both ends, open pipes resonate at exact half-wavelength intervals, allowing for all harmonics ($f_1, f_2, f_3, \dots$).

String Instruments: Fixed Boundaries

Concept: Strings are fixed at both ends (e.g., the bridge and nut of a guitar). Therefore, **both ends MUST be Displacement Nodes**.



Fundamental:

$$\lambda_1 = 2L \quad | \quad f_1 = \frac{v}{2L}$$

2nd Harmonic:

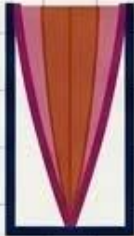
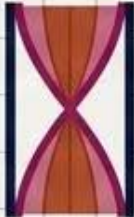
$$\lambda_2 = L \quad | \quad f_2 = \frac{v}{L} = 2f_1$$

3rd Harmonic:

$$\lambda_3 = \frac{2L}{3} \quad | \quad f_3 = \frac{3v}{2L} = 3f_1$$

Insight: Notice the math! The frequency equations for a string are identical to an open pipe, because both require symmetric boundary conditions (Node-Node vs. Antinode-Antinode).

The Mr. Mohamad Resonance Matrix

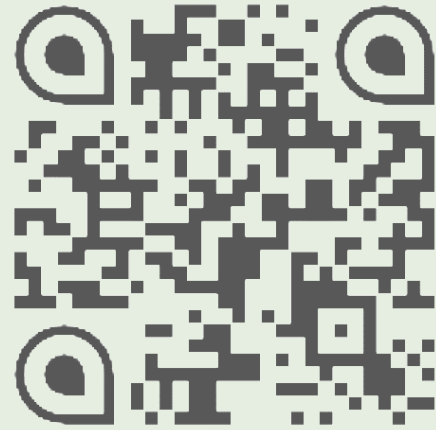
System Type	Boundary Conditions	Visual of Fundamental	Wavelength (λ_1)	Harmonics Allowed
Closed Pipe	Node to Antinode		$4L$	Odd only ($f_1, 3f_1, 5f_1$) $\rightarrow f_n = n(v/4L)$
Open Pipe	Antinode to Antinode		$2L$	All ($f_1, 2f_1, 3f_1$) $\rightarrow f_n = n(v/2L)$
String	Node to Node		$2L$	All ($f_1, 2f_1, 3f_1$) $\rightarrow f_n = n(v/2L)$

Mastering these three systems unlocks the fundamental physics of all musical instruments.

Module (15): Fundamentals of Light

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15-2	The Wave Nature of Light	79

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Module (15): Fundamentals of Light

01 First Lesson: Illumination



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PHYSICS ADVANCED: Illumination & The Speed of Light

A Comprehensive Student Master Guide
(Concepts, Formulas &
Worked Examples)

Module 15 | Lesson 1

Prepared by Mr. Mohamad



THE RAY MODEL OF LIGHT

Light is electromagnetic radiation (like radio and microwaves) that can be modeled as both waves and particles (photons).

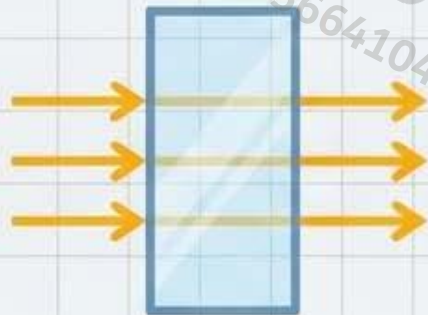
THE GOLDEN RULE

LIGHT TRAVELS IN STRAIGHT LINES UNTIL IT INTERACTS WITH MATTER.

LIGHT PATHS AND SHADOWS

We see the path of a narrow beam of light—like a flashlight or sunlight through a window—only when it scatters off particles in the air. Shadows form precisely because light cannot bend around objects.

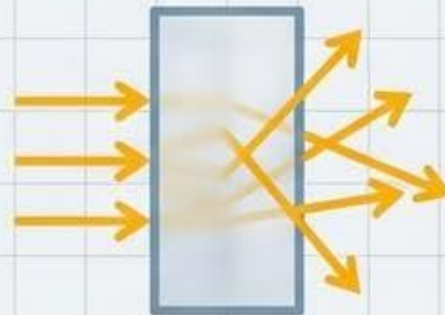
Light & Matter Interaction



Transparent

Transmits most light that reaches it. Objects can be seen clearly through it.

(Examples: Air, clear glass)



Translucent

Transmits and reflects light, but scatters it. Objects cannot be seen clearly.

(Examples: Frosted glass, lampshades)



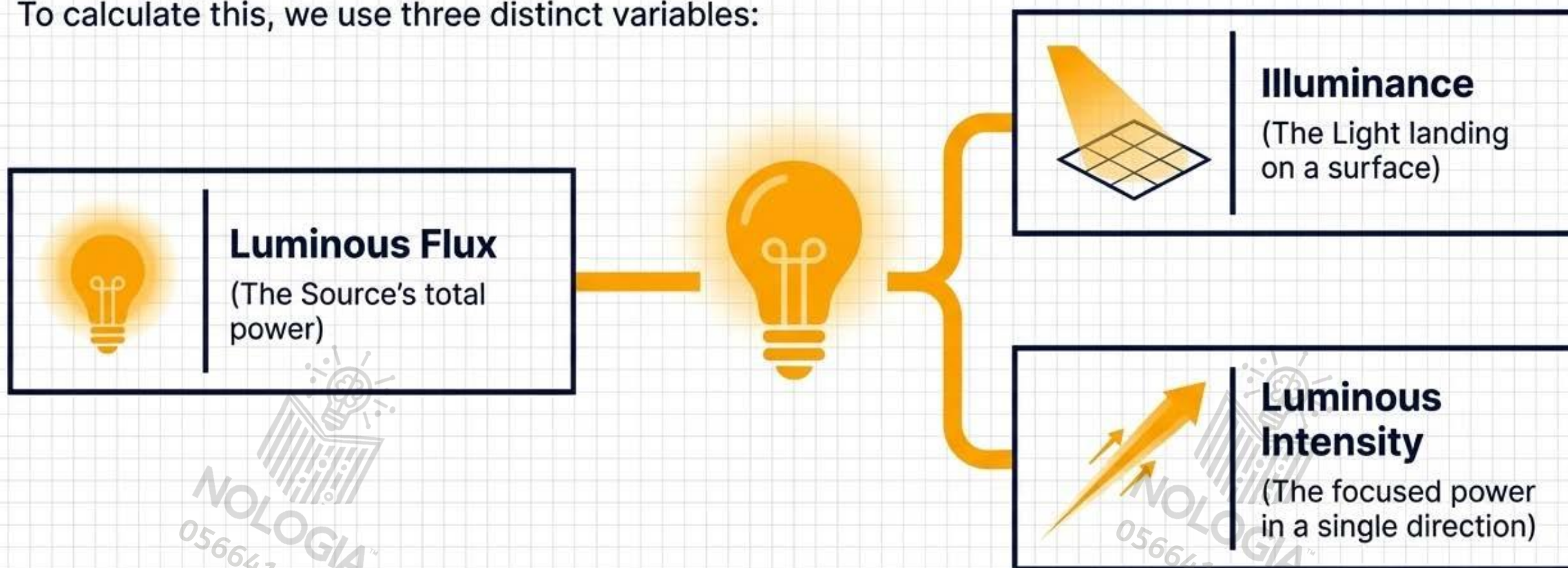
Opaque

Absorbs or reflects all light. Does not transmit any light.

(Examples: Books, people, backpacks)

The Three Pillars of Light Measurement

The brightness of a light depends on three main factors: the total quantity of light produced, the distance to your eye, and the angle of the rays. To calculate this, we use three distinct variables:



1. Luminous Flux (P)

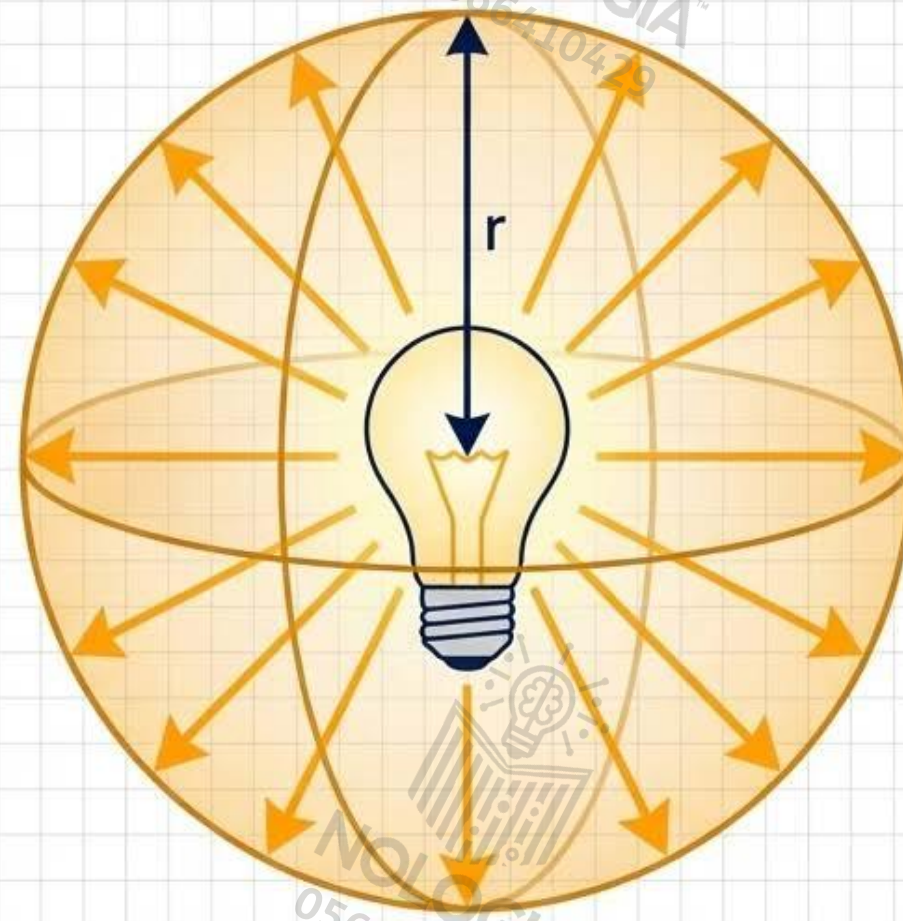
Definition: The rate at which a luminous source produces light energy.

Symbol: P

Unit: Lumens (lm)

KEY INSIGHT

Luminous flux is entirely dependent on the source itself. It represents all the light rays sent out in nearly all directions. A 100W bulb produces more luminous flux than a 60W bulb, regardless of where you stand to look at it.



2. Illuminance (E)

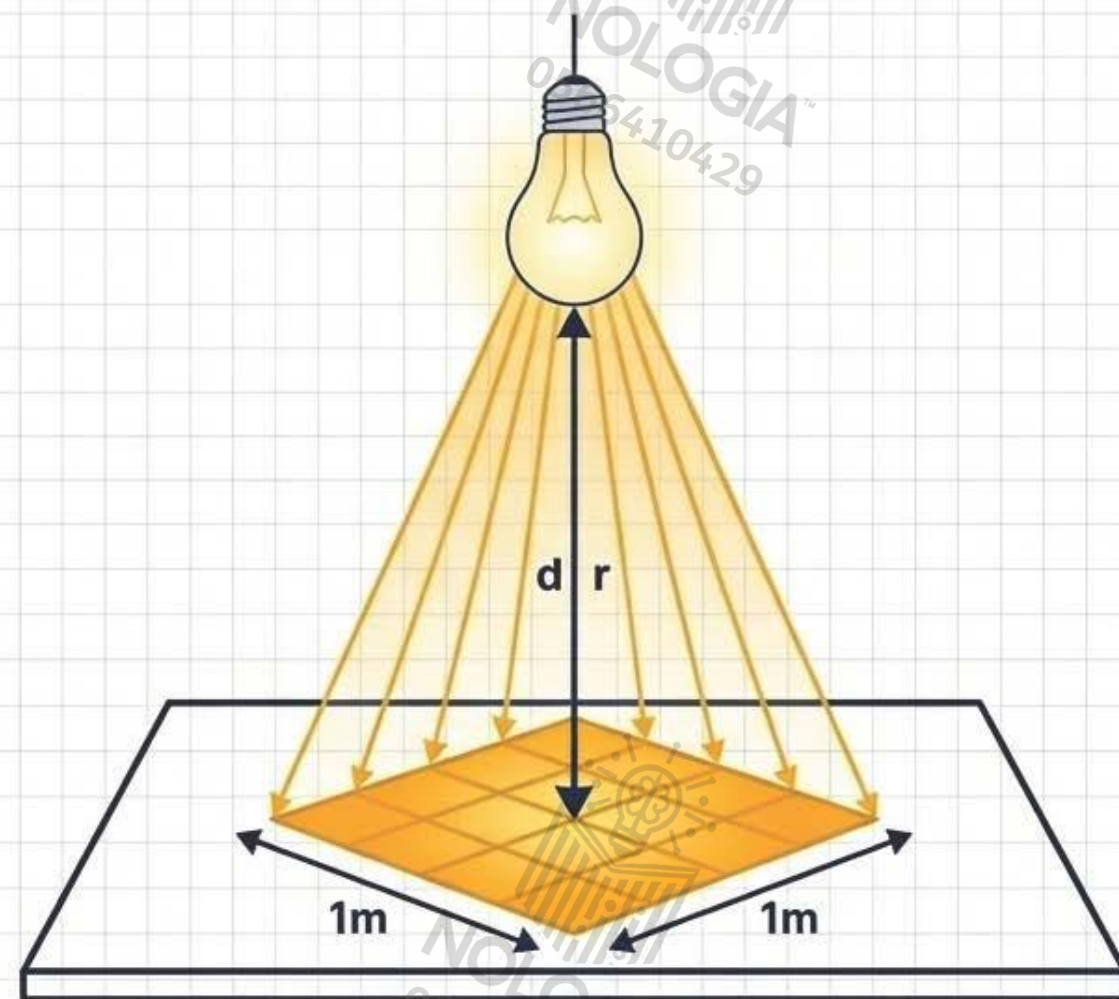
Definition: The amount of illumination a source provides to a given surface area at any instant.

Symbol: E

Unit: Lux (lx), which is equivalent to lumens per square meter (lm/m^2).

KEY INSIGHT

Unlike Flux, Illuminance depends on distance. It represents the total amount of light that actually strikes a surface. If you move the surface further away, the Illuminance decreases.



The Inverse-Square Relationship

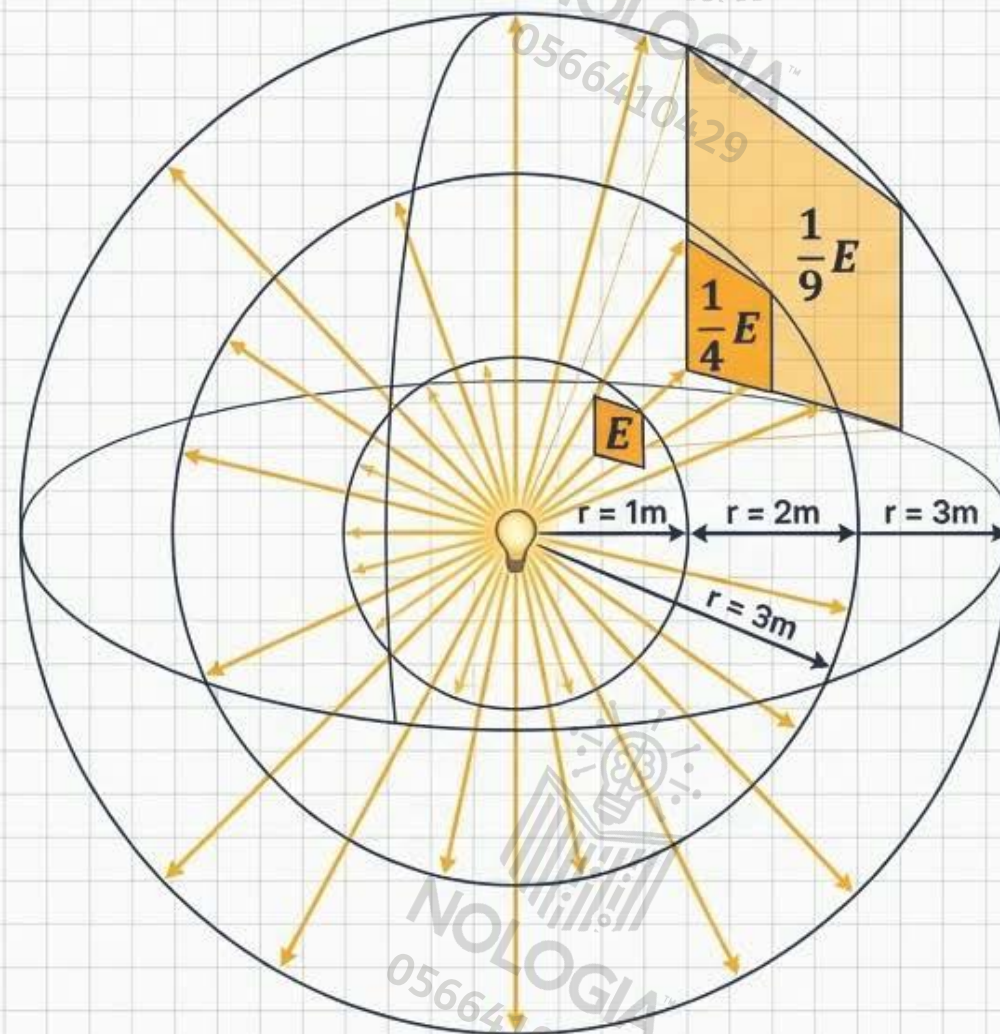
$$E = \frac{P}{4\pi r^2}$$

THE RULE

Light spreads out in all directions. If the distance (r) from the bulb doubles, the surface area of the surrounding sphere becomes four times larger ($4\pi(2r)^2 = 16\pi r^2$).

Therefore, illuminance (E) is inversely proportional to the square of the distance (r^2).

At 2m, illuminance is $\frac{1}{4}$ as bright. At 3m, it is $\frac{1}{9}$ as bright.



3. Luminous Intensity (I)

Definition:

The luminous flux that falls on 1 m^2 of the inside of a 1-m-radius sphere. It measures focused intensity in a specific direction.

Symbol:

I

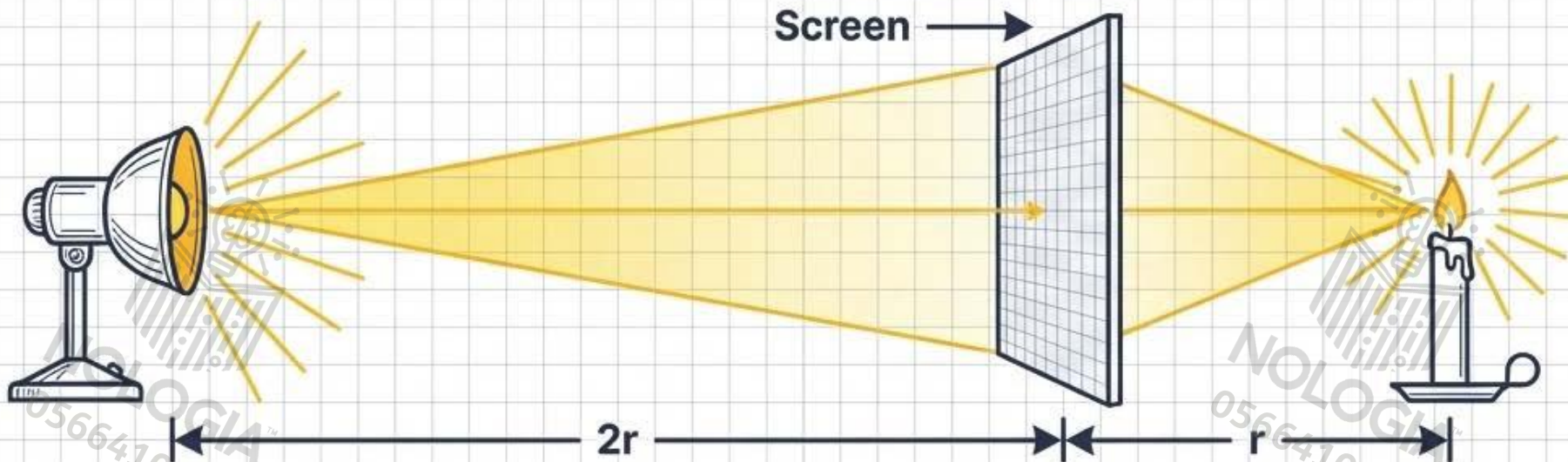
Unit:

Candelas (cd)

Equation:

$$I = \frac{P}{4\pi}$$

SCENARIO CALLOUT: To provide the same illuminance on a screen from twice the distance ($2r$), a lightbulb must have four times the luminous intensity of the closer light source.



Mr. Mohamad's Formula Master-Board

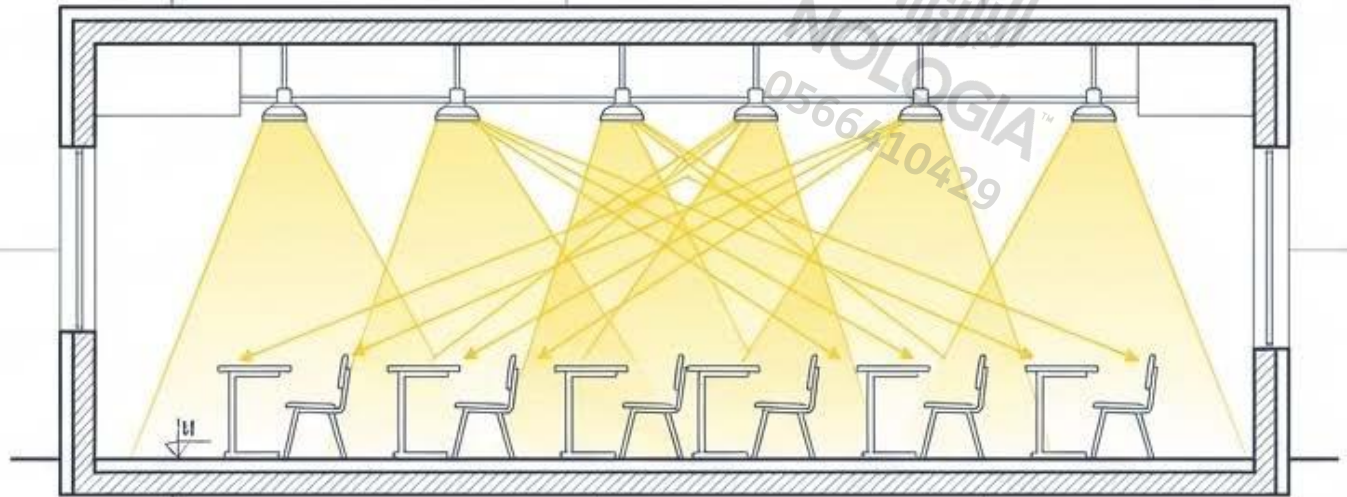
Property	Symbol & Unit	Equation & Notes
Luminous Flux	P in Lumens (lm)	(Total Source Power)
Illuminance	E in Lux (lx or lm/m ²)	$E = \frac{P}{4\pi r^2}$
Luminous Intensity	I in Candelas (cd)	$I = \frac{P}{4\pi}$

POINT-SOURCE ASSUMPTION: These mathematical models are only valid if we assume the light source is small enough or far enough away to be considered a point source. They lose accuracy for long fluorescent tubes or bulbs extremely close to a surface.

Real-World Engineering: Surface Illumination

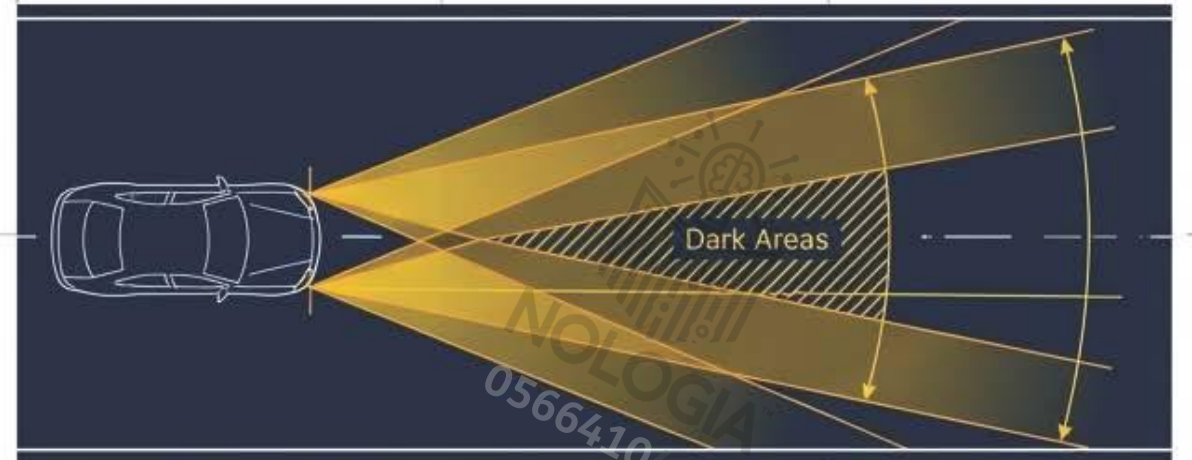
Illuminated Minds

Architects must calculate the exact luminous flux of lights and their distance to desktops to ensure minimum legally required illuminance (lx) for studying without eye strain.



Automotive Lighting

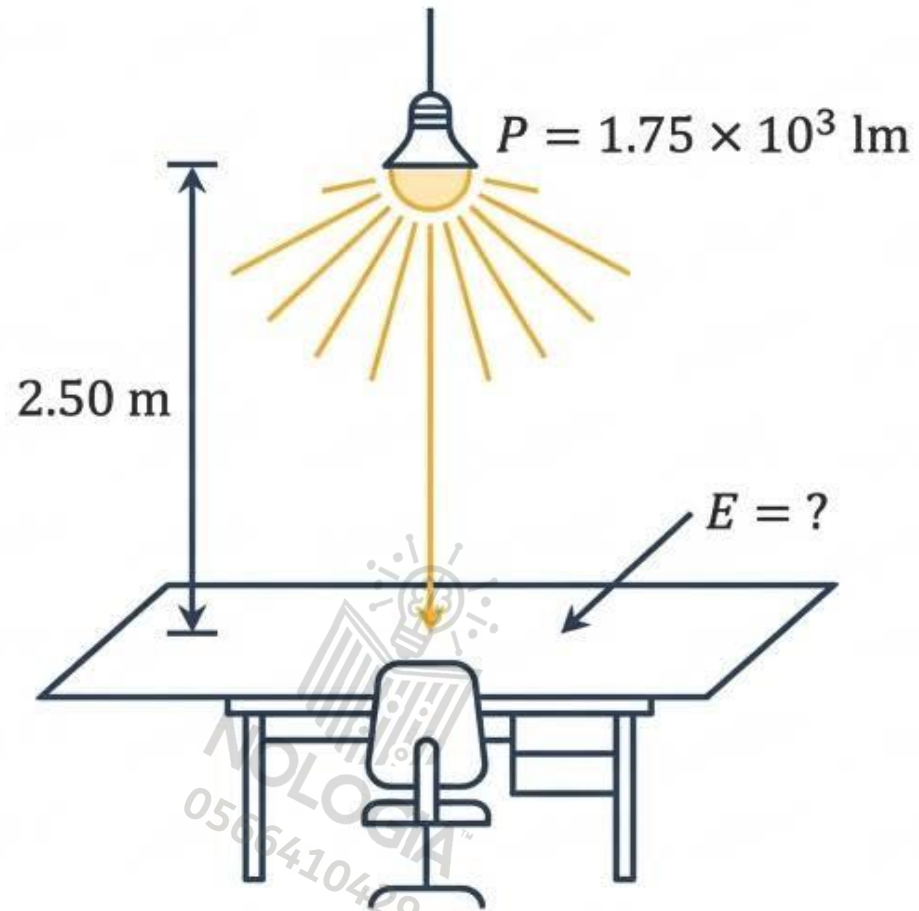
Automotive engineers use these formulas to design headlight throw. Headlights must be spaced and angled perfectly to overlap and prevent dangerous dark areas on the road, while accounting for the inverse-square drop-off in brightness.



Master Example 1: Desktop Illuminance

The Problem: What is the illuminance on your desktop if it is lit by a 1750-lm lamp that is 2.50 m above your desk?

Analyze



Solve

Step 1: Identify Knowns

$P = 1750 \text{ lm}$, $r = 2.50 \text{ m}$. Find E .

Step 2: Apply Point-Source Equation

$$E = \frac{P}{4\pi r^2}$$

Step 3: Substitute & Solve

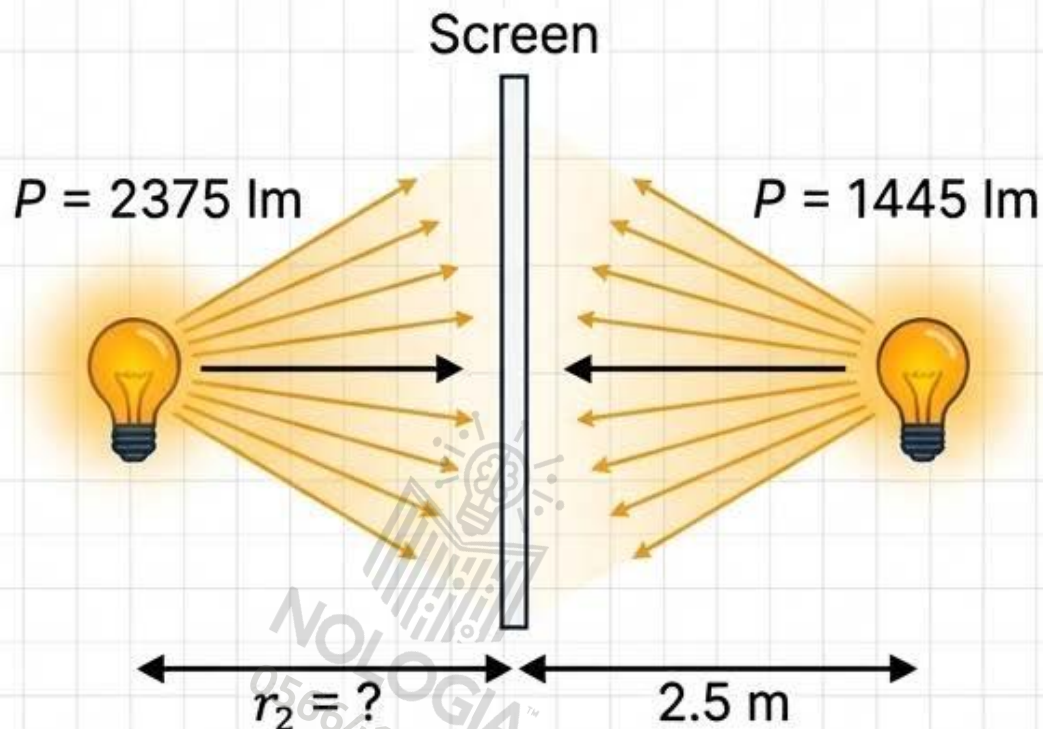
$$E = \frac{1750}{4\pi(2.50)^2}, \quad E = \frac{1750}{78.54}, \quad E = 22.3 \frac{\text{lm}}{\text{m}^2}$$

Final Answer: $E = 22.3 \text{ lx}$

Master Example 2: Balancing Two Sources

The Problem: A screen is placed between two lamps so they illuminate it equally. Lamp 1 (1445 lm) is 2.5m away. What is the distance of Lamp 2 (2375 lm)?

Analyze



Solve

Step 1: The Logic

Illuminate equally means $E_1 = E_2$

$$\frac{P_1}{r_1^2} = \frac{P_2}{r_2^2} \rightarrow r_2 = \frac{P_1}{r_1^2}$$

Step 3: Simplify

$$\frac{P_1}{r_1^2} \rightarrow \frac{1445}{2.5^2} = \frac{2375}{r_2^2}$$

Step 2: Setup

$$\frac{P_1}{4\pi r_1^2} = \frac{P_2}{4\pi r_2^2}$$

(Notice the 4π cancels out on both sides!)

Step 4: Solve

$$231.2 = \frac{2375}{r_2^2}$$

$$r_2^2 = 10.27$$

$$r_2 = 3.2\text{m}$$

The Speed of Light (c): A Historical Quest

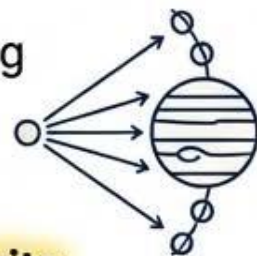
Context: For more than 2400 years, humanity debated whether light traveled instantaneously or at a finite speed. Because light is incredibly fast, measuring it over short Earth distances was impossible with early technology.

Ancient Beliefs

Assumed light speed was **infinite and instantaneous**.

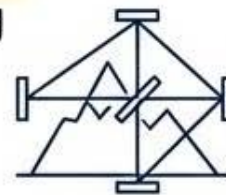
1670s: Ole Roemer

First successful measurement using astronomical distances (Jupiter's moons). Proved **speed is finite**.

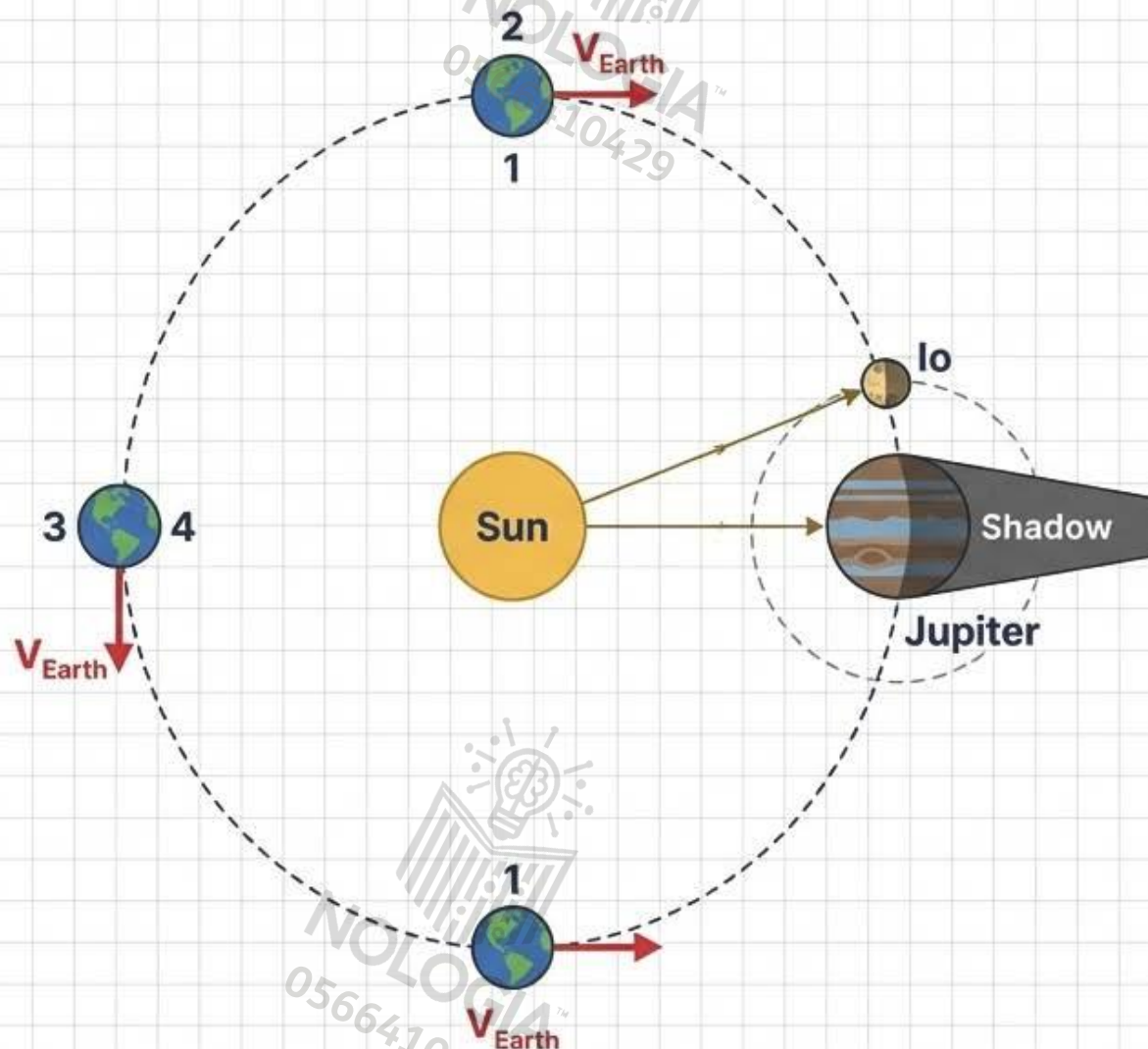


1920s: Albert A. Michelson

Precise Earth-based measurement using high-tech mountain mirrors, establishing the **universal constant**.



Roemer's Cosmic Clock (1668-1674)



The Observation:

Danish astronomer Ole Roemer recorded the times when the moon Io emerged from Jupiter's shadow.

The Anomaly:

He noticed the eclipses took about 13 seconds longer when Earth was moving away from Jupiter, and 13 seconds shorter when moving toward it.

The Breakthrough Conclusion:

Jupiter's moons act as a perfect clock. The 13-second delay was exactly the time it took light to travel the extra distance across Earth's expanding orbit!

The First Calculation:

$$2.2 \times 10^8 \text{ m/s}$$

Michelson & The Universal Constant



The Earth Experiment

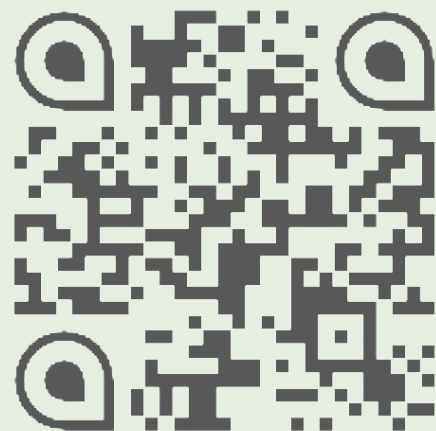
Between 1880 and the 1920s, American physicist Albert A. Michelson precisely measured the time required for light to make a round trip between two California mountains 35 km apart. (He became the first American to win a Nobel Prize in science for this work).

The Defined Constant (Vacuum)

$$c = 3.00 \times 10^8 \frac{\text{m}}{\text{s}}$$

Final Concept (The Light-Year)

Because c is constant, we use it to measure massive cosmic distances. A light-year is the distance light travels in one year: 9.46×10^{12} km.



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Module (15): Fundamentals of Light

02

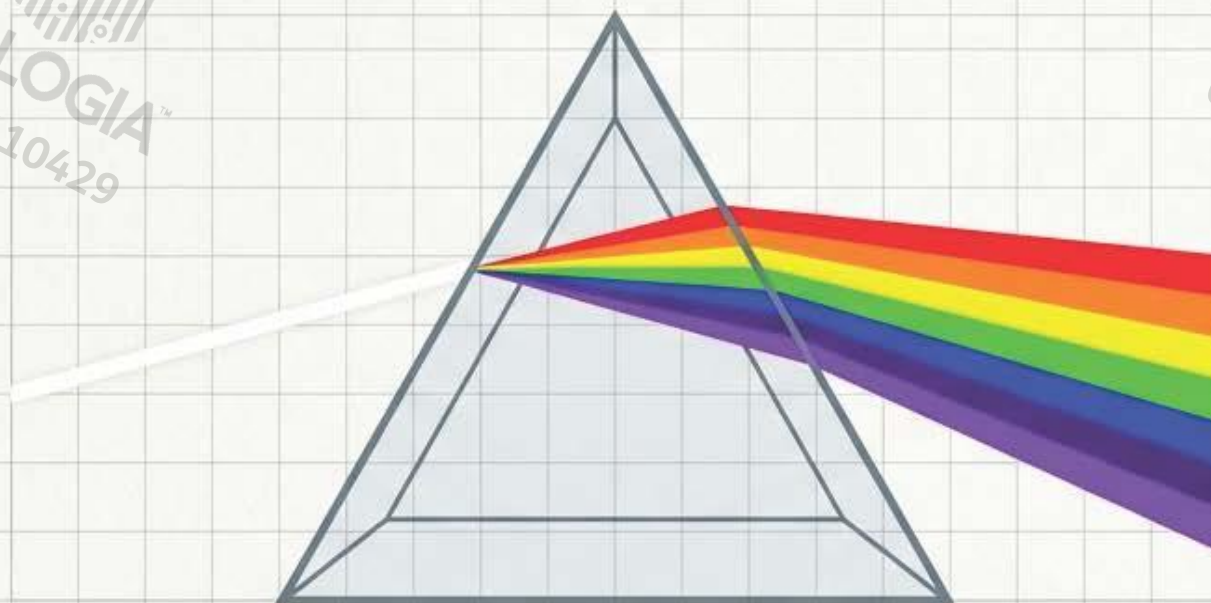
Second Lesson:
The Wave Nature of Light



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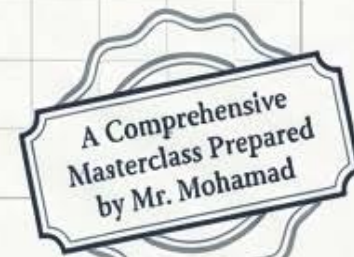
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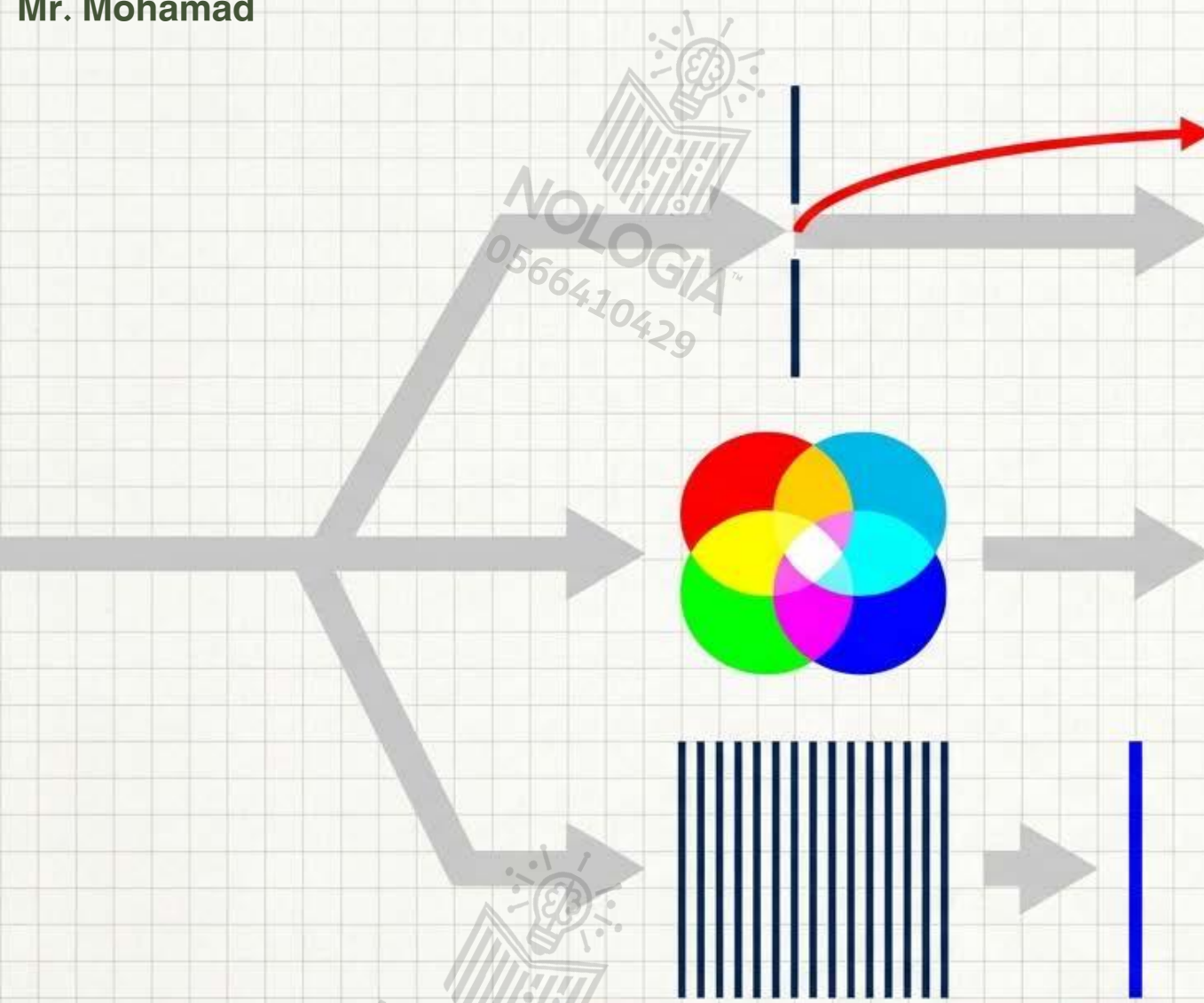




The Wave Nature of Light

Diffraction, Color, and Polarization





Bending: Diffraction & The Wave Model

Light waves spread out after passing through a narrow aperture or around an obstacle.

Interacting: The Science of Color

The interaction of different wavelengths of light results in the perception of various colors, illustrated by additive color mixing.

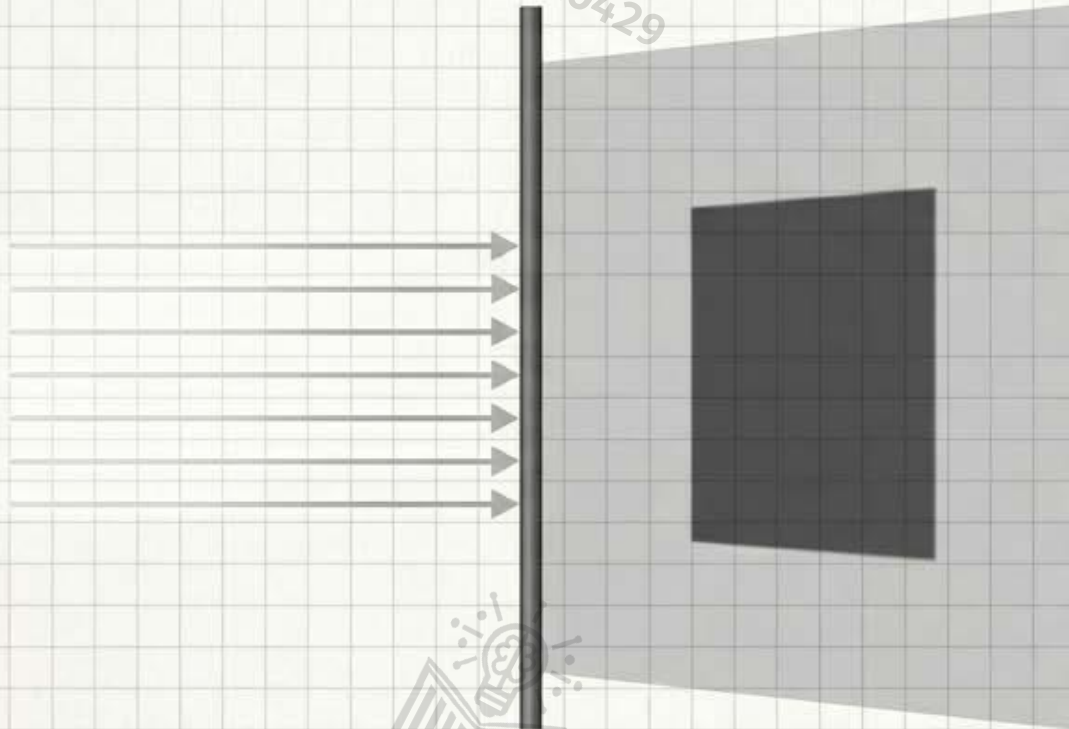
Filtering: Polarization

Polarization restricts the vibration of light waves to a single plane, allowing only waves oriented in a specific direction to pass through.

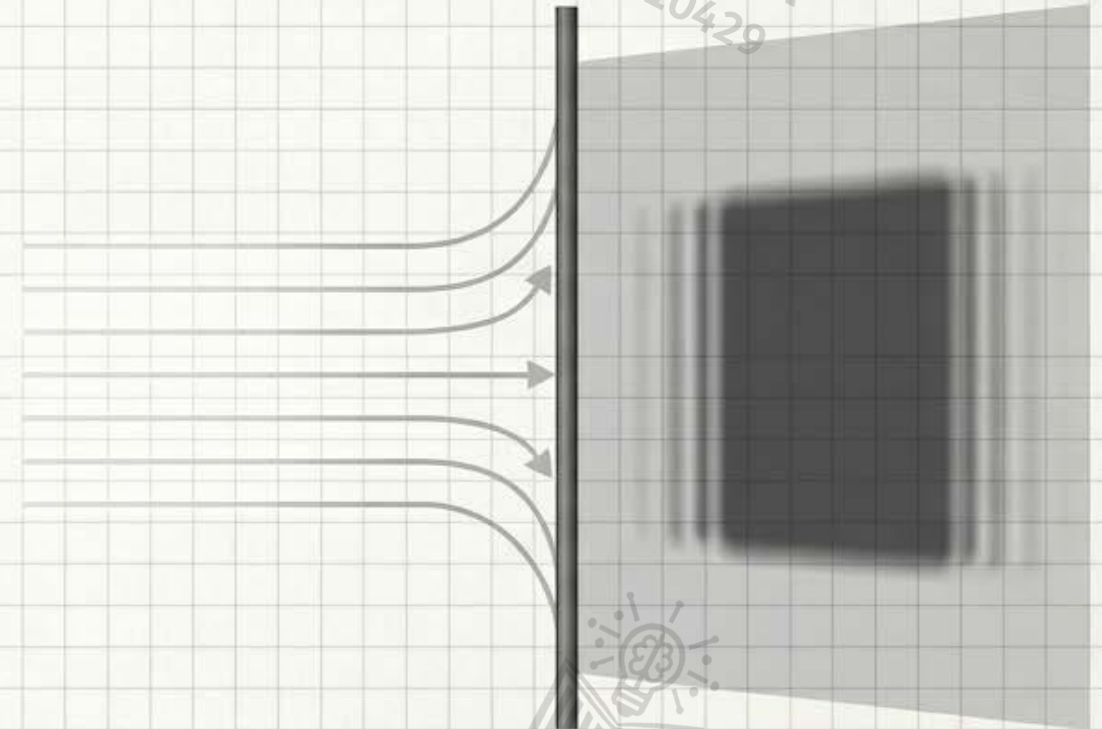
If light were purely a particle, none of these phenomena would exist. We must treat light as a **transverse wave**.

Light Does Not Always Travel in a Straight Line

The Expectation (Particle Theory)

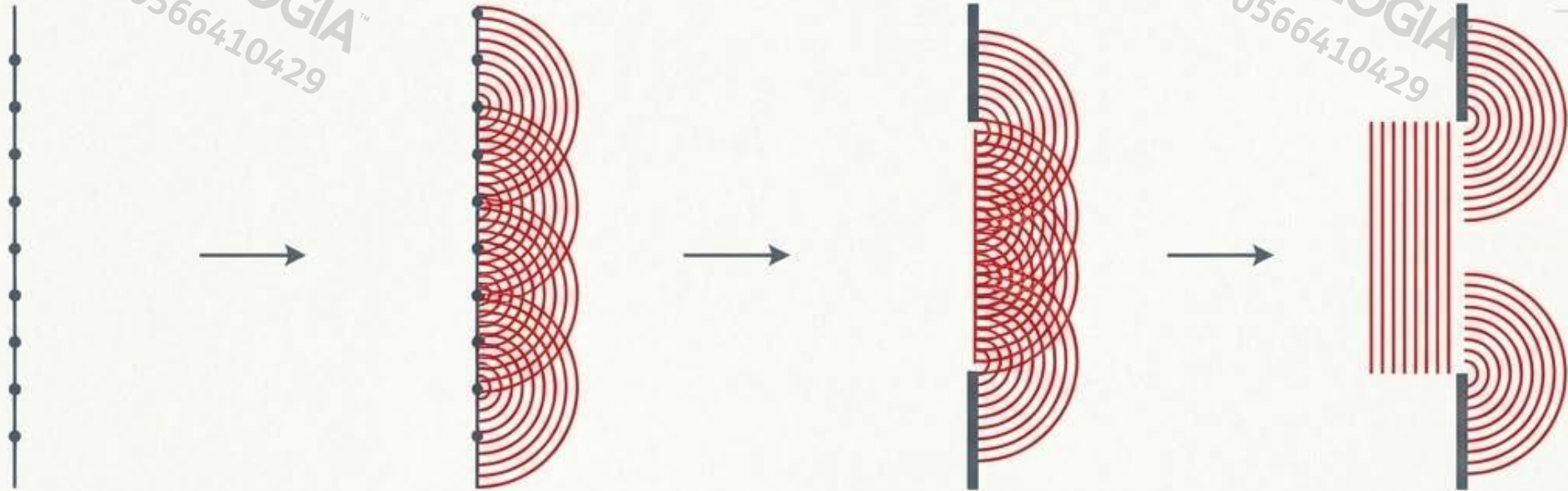


The Reality (Wave Theory)



Diffraction: The bending of light as it passes the edge of a barrier.

Huygens' Principle: The Anatomy of a Bending Wave



1. A flat wavefront consists of infinite point sources.

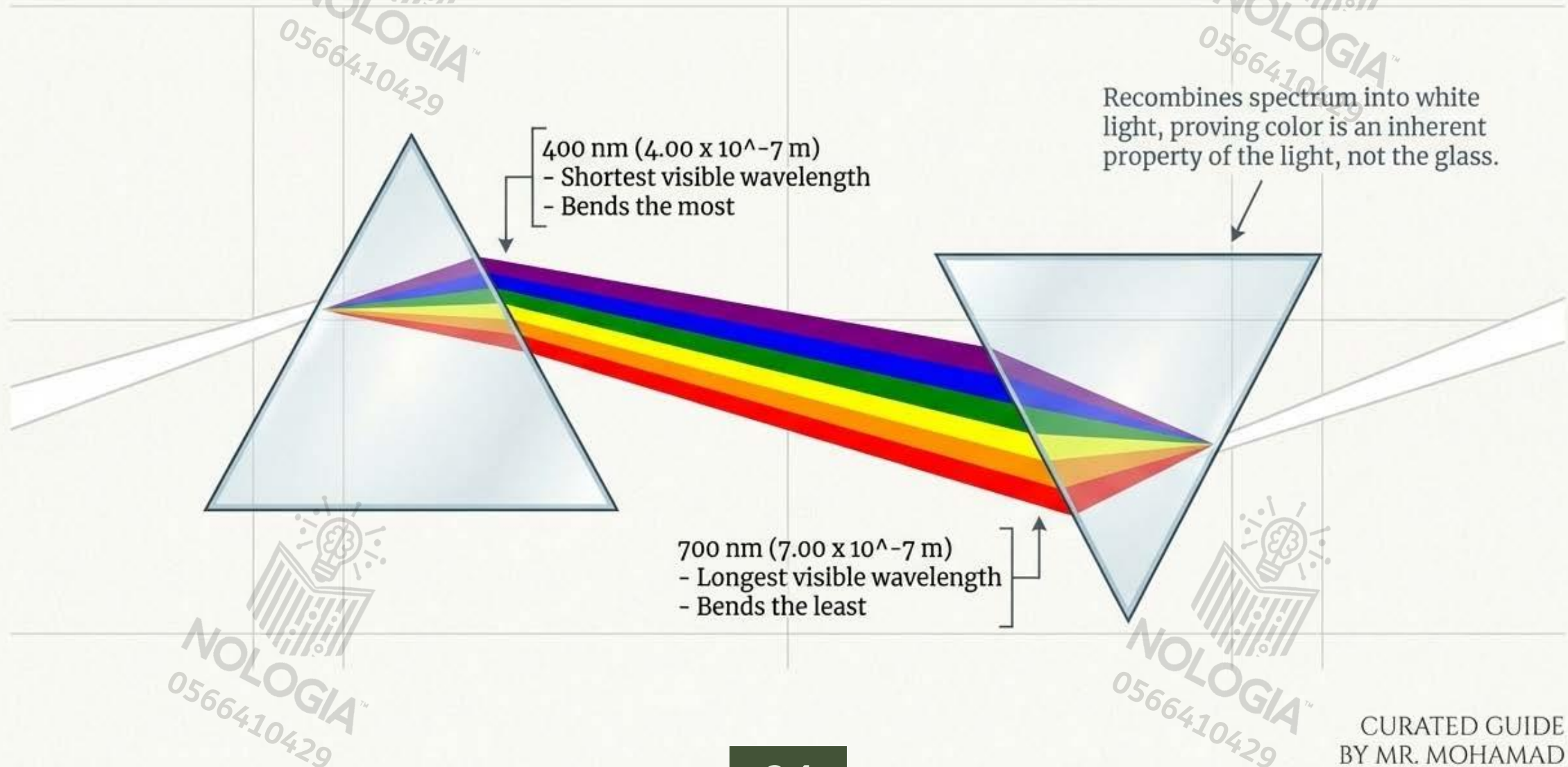
2. Each point generates smaller, circular wavelets.

3. Wavelets combine to form a new straight wavefront.

4. At the edge, the wavelet spreads out in a circular manner, creating the bend.

Core Rule: Every point on a wavefront of light acts as a new source of smaller, circular wavelets.

Newton's Insight: White Light is a Composite



Color by Addition (Mixing Light)



Secondary Colors:

Red + Green = Yellow

Blue + Green = Cyan

Red + Blue = Magenta

Complementary Rule:

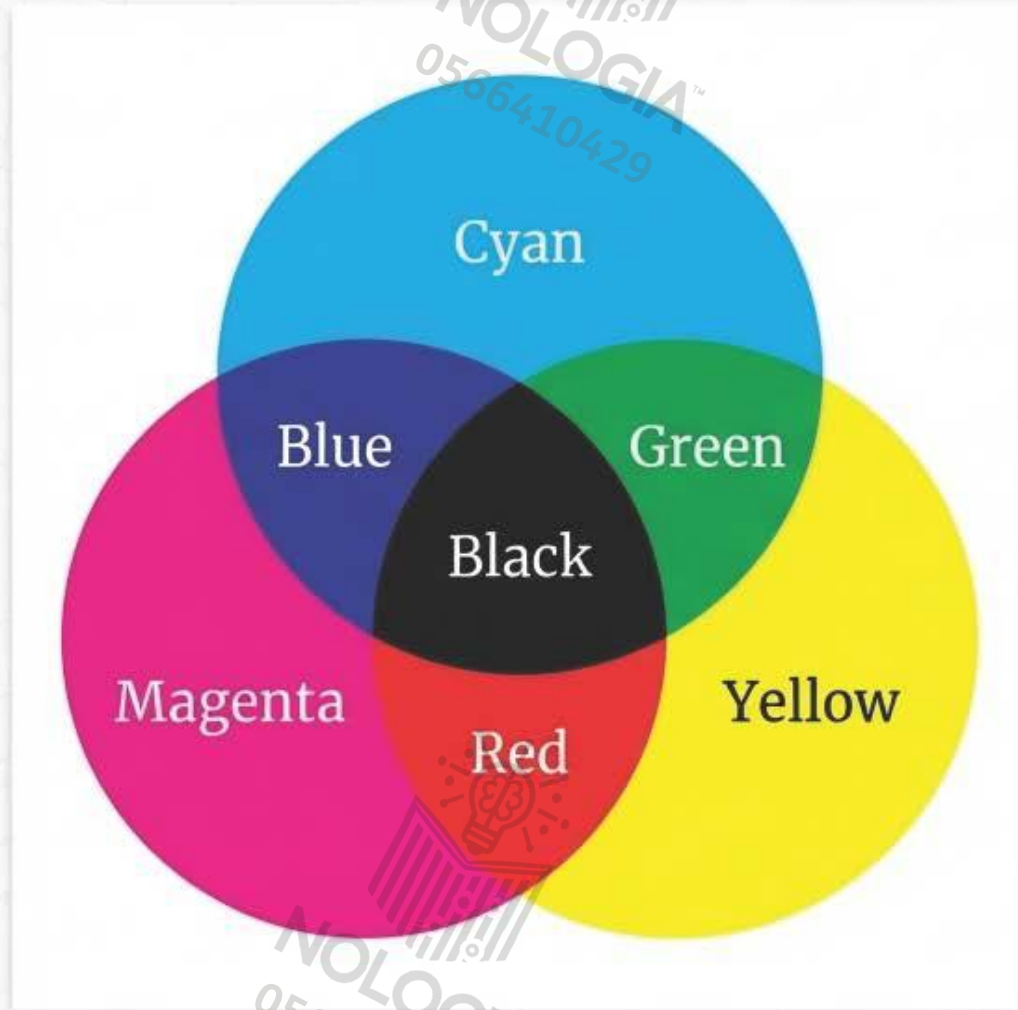
Complementary Colors: Any two colors of light that combine to produce white.

Example: Yellow + Blue = White.



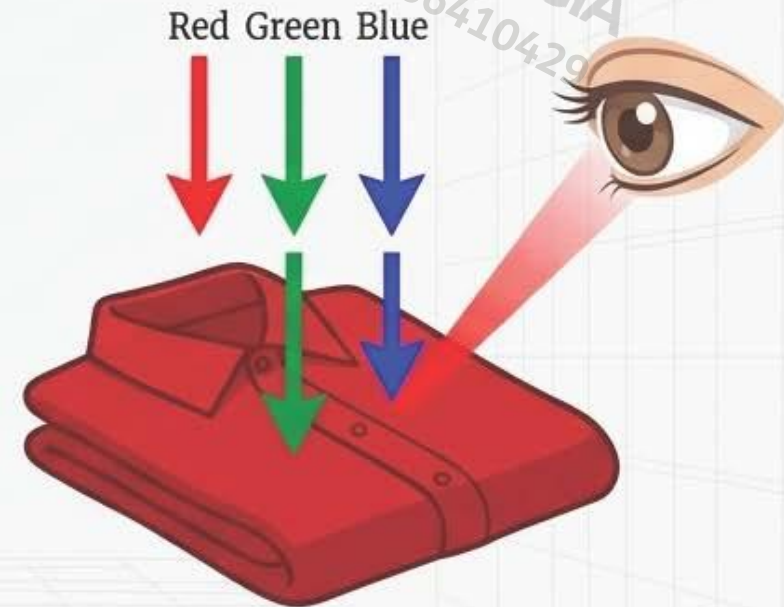
Real-World Application: Television screens project tiny individual pixels of Red, Green, and Blue light to create all visible images.

Color by Subtraction (Pigments & Dyes)



Subtractive Color Mixing (Pigments & Dyes)

Why is a red shirt red?



Definition: A dye or pigment absorbs specific wavelengths of light and reflects or transmits others.

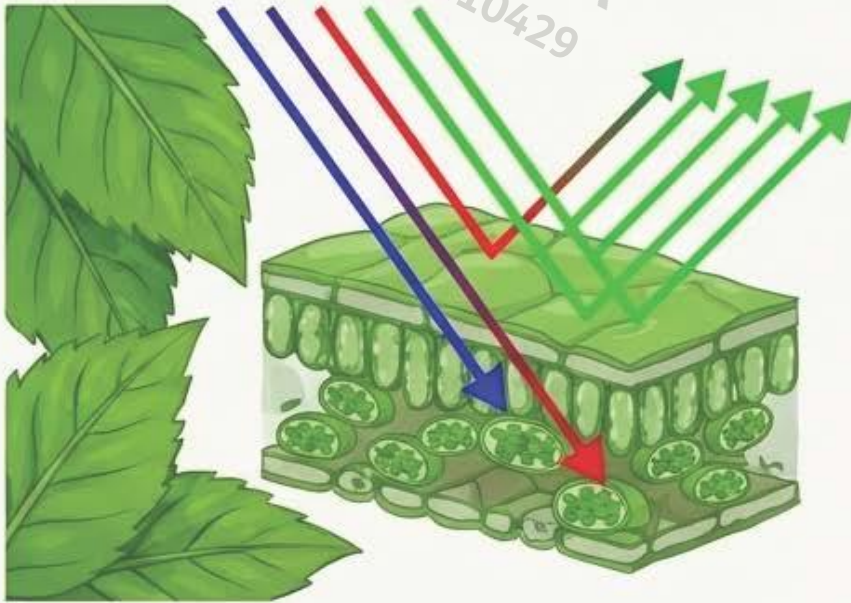
Examples: Natural purple extracts from black mulberry, red dye from cochineal insects, and crushed minerals like hematite.

The Master Matrix: Light vs. Pigments

Feature	Color by Addition (Light)	Color by Subtraction (Pigments)
Primary Base	Red, Green, Blue  +  + 	Cyan, Magenta, Yellow  +  + 
Secondary Result	Cyan, Magenta, Yellow  +  + 	Red, Green, Blue  +  + 
Combination Result	All 3 Primaries = White  +  +  = 	All 3 Primaries = Black  +  +  = 
Complementary Example	Yellow + Blue = White  +  = 	Yellow + Blue = Black  +  = 

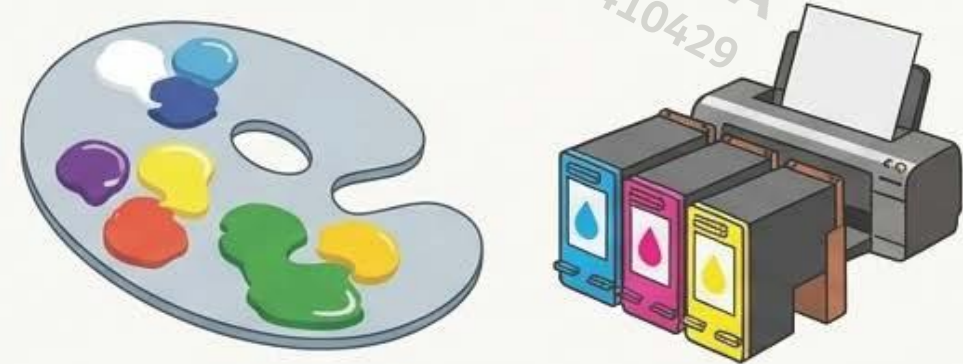
Science Connections: Color in the Real World

Biology Connection



Chlorophyll mostly absorbs red and blue light, while reflecting green light during photosynthesis.

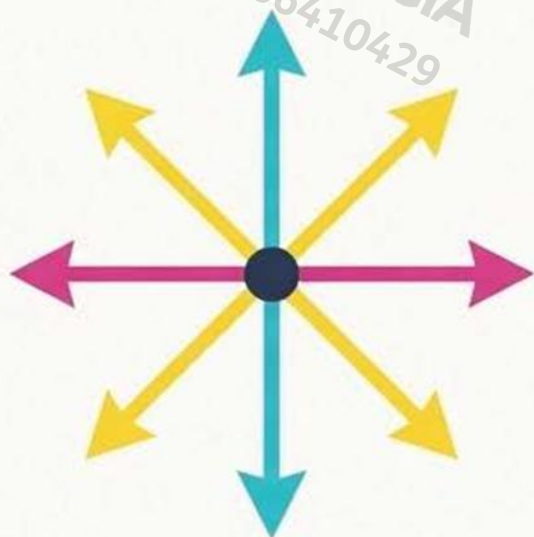
Chemistry Connection



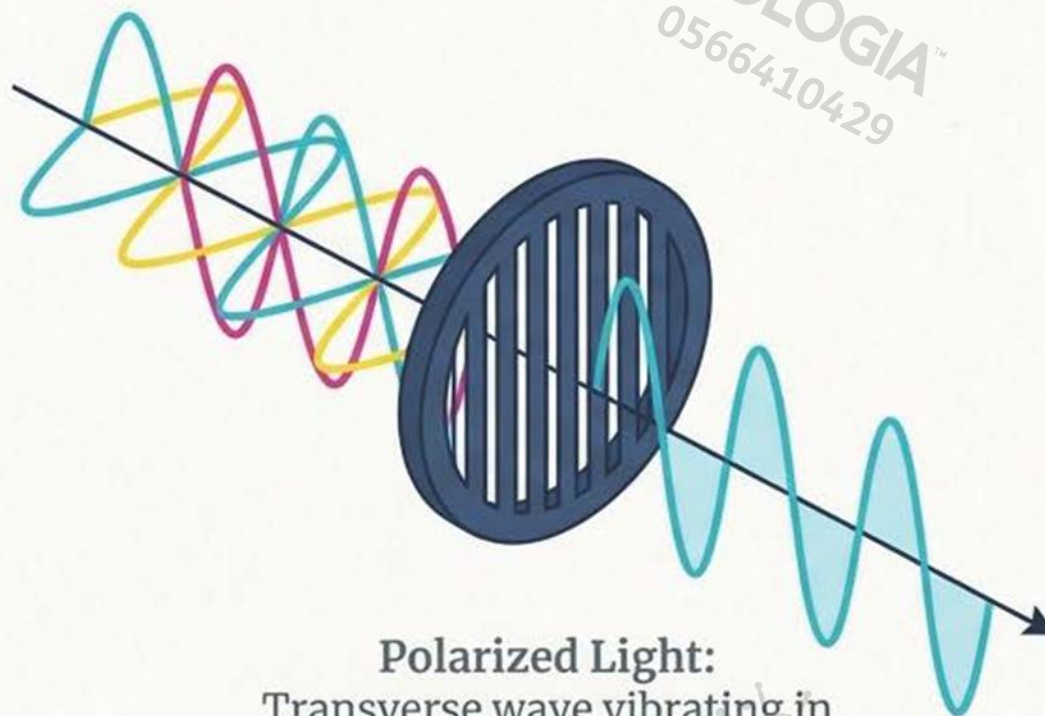
- Titanium(IV) oxide creates White pigment.
- Chromium(III) oxide creates Green pigment.
- Cadmium sulfide creates Yellow pigment.

Color printers use exact microscopic dots of Cyan, Magenta, and Yellow pigment to synthesize full-color images.

Taming the Wave: The Principle of Polarization



Unpolarized Light:
Electric field oscillates randomly
in every direction.

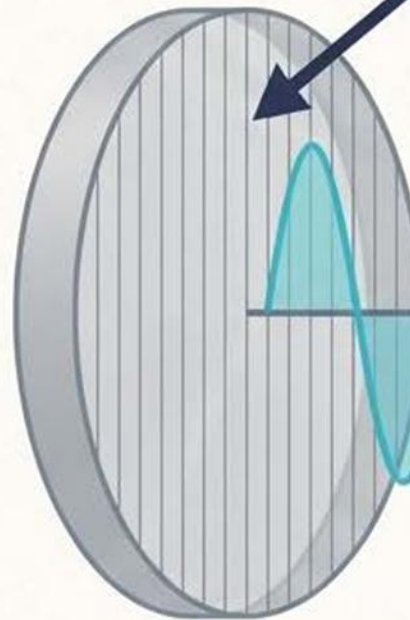
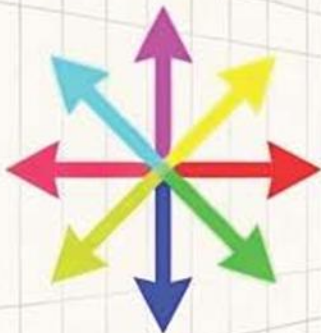


Polarized Light:
Transverse wave vibrating in
a single plane.

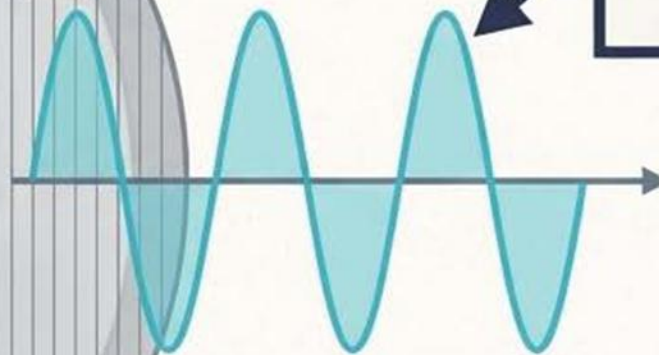
Polarization – The production of light oscillating with a specific pattern, restricted to one plane of vibration.

Polarization by Filtering

Intensity = I_0



Polarizing
Axis

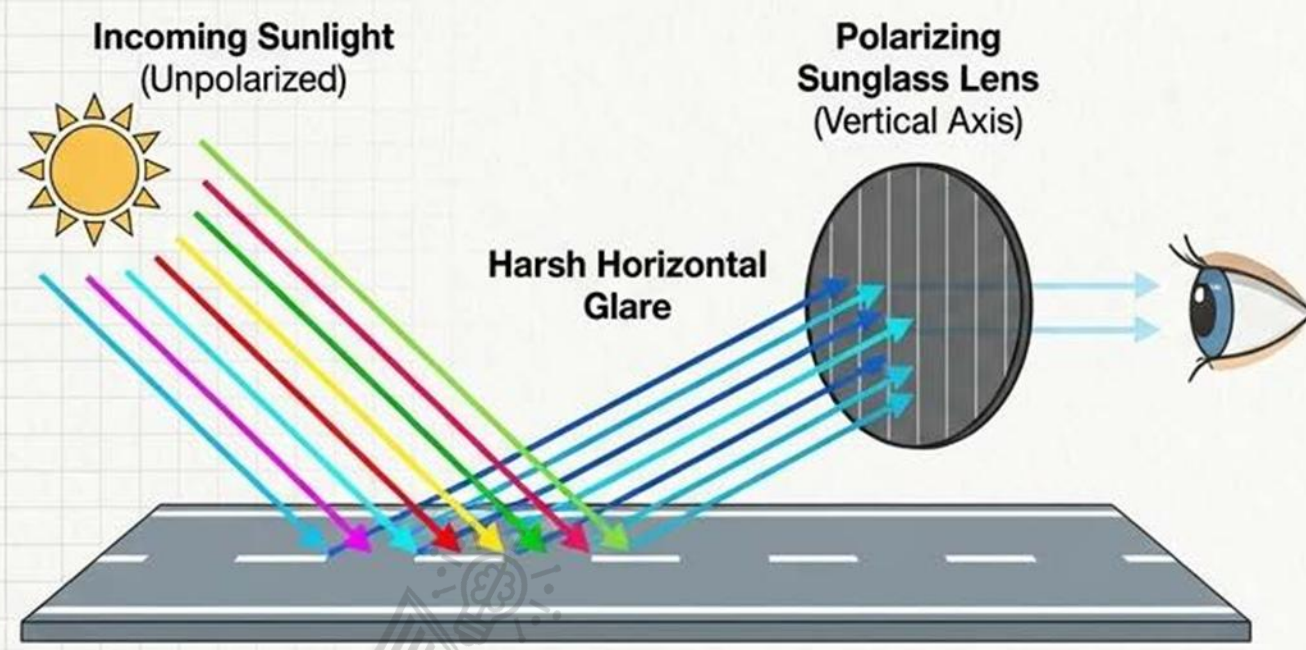


Transmitted Light:
Intensity Reduced
by Exactly 50%

Mechanics:

Long molecules in polarizing mediums absorb waves oscillating in the same direction as their electrons. Only waves oscillating perpendicular to the long molecules (parallel to the polarizing axis) pass through.

Polarization by Reflection: Defeating Glare



Horizontal glare is blocked by the vertical transmission axis of the sunglasses.



Without Polarizing Filter
(Light is polarized parallel to the glass)

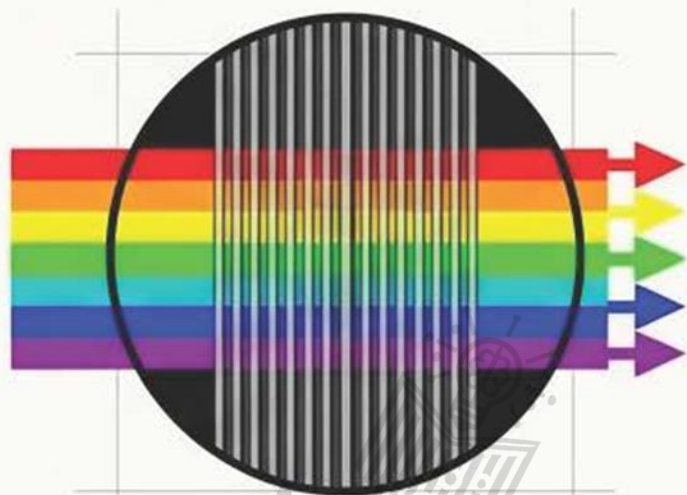


With Polarizing Filter
(Glare is blocked)

The Math of Filtering: Malus's Law

$$I_2 = I_1 \cos^2 \theta$$

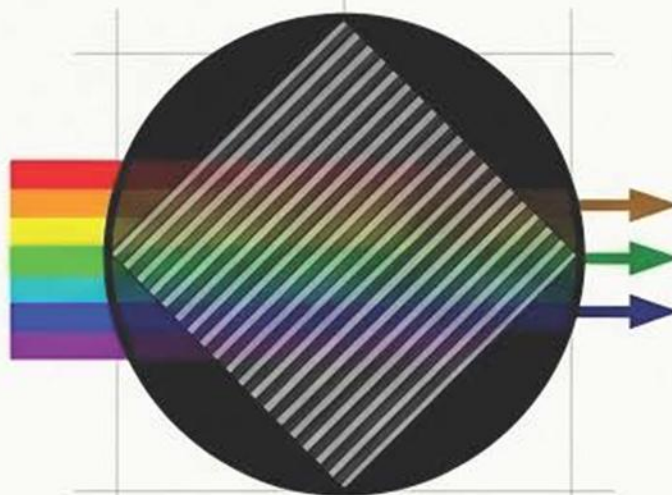
The intensity (I_2) coming out of a second filter equals the incoming polarized intensity (I_1) multiplied by the cosine squared of the angle (θ) between their axes.



Dial 1

Axes Parallel (0°)

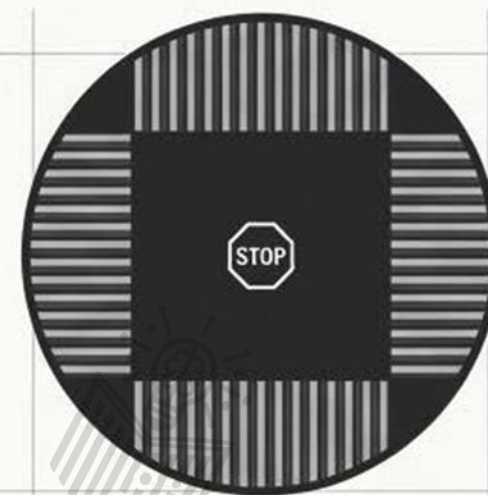
$\cos^2(0^\circ) = 1 \rightarrow 100\%$ Passes



Dial 2

Axes at 45°

$\cos^2(45^\circ) = 0.5 \rightarrow 50\%$ Passes



Dial 3

Axes Perpendicular (90°)

$\cos^2(90^\circ) = 0 \rightarrow 0\%$ Passes

Masterclass Summary: The Wave Nature of Light

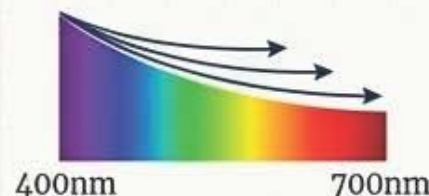
Diffraction (Bending)

- Light bends around edges, proving it behaves as a transverse wave.
- **Huygens' Principle:** Every point on a wavefront acts as a new source of circular wavelets.



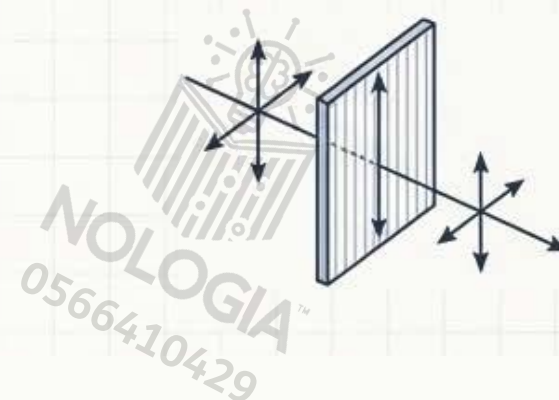
Color Rules (Interacting)

- **Light (Addition):** **R** **G** **B** mix to form White. Complementary colors = **Yellow** + **Blue**.
- **Pigments (Subtraction):** **C** **M** **Y** mix to form Black. Objects absorb specific wavelengths.
- **Wavelengths:** 400nm (Violet, bends most) to 700nm (Red, bends least).

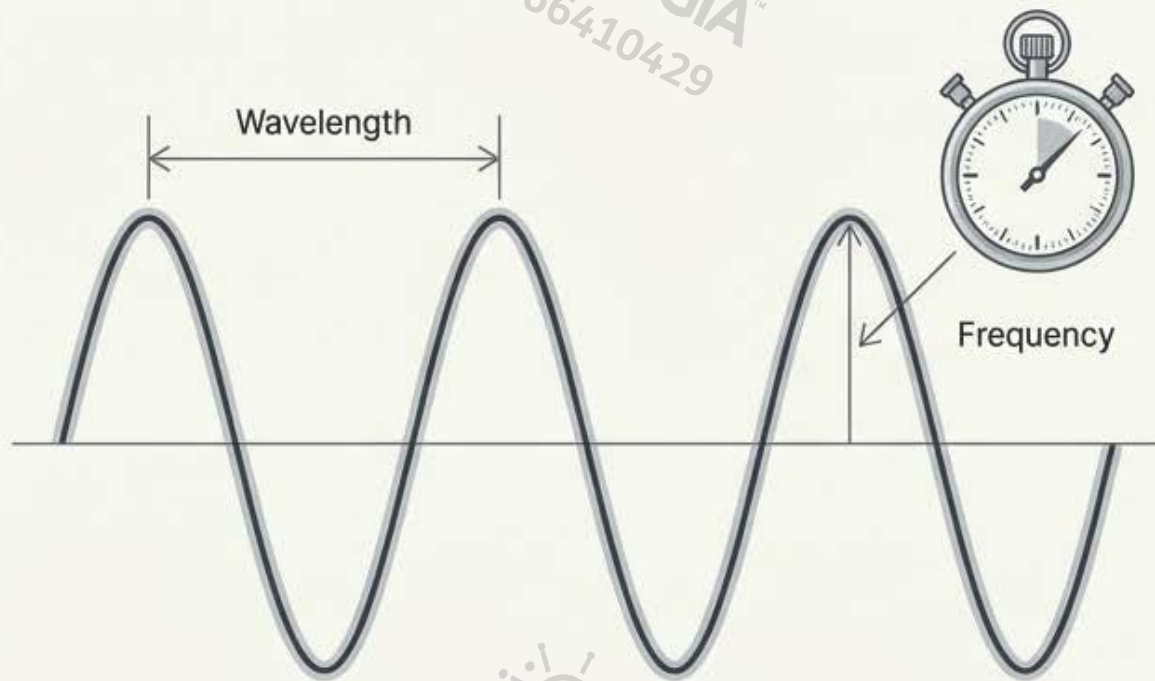


Polarization (Filtering)

- Filters reduce unpolarized light intensity by exactly 50%.
- Reflected glare is polarized parallel to the reflecting surface.
- **Malus's Law:** $I_2 = I_1 \cos^2 \theta$



The Holy Trinity of Light Waves



$$c = \lambda f$$

c = Speed of Light

Constant in a vacuum for all colors. Measured today with extreme precision using lasers and atomic clocks.

λ = Wavelength

Determined by the medium it travels through and the frequency of the wave.

f = Frequency

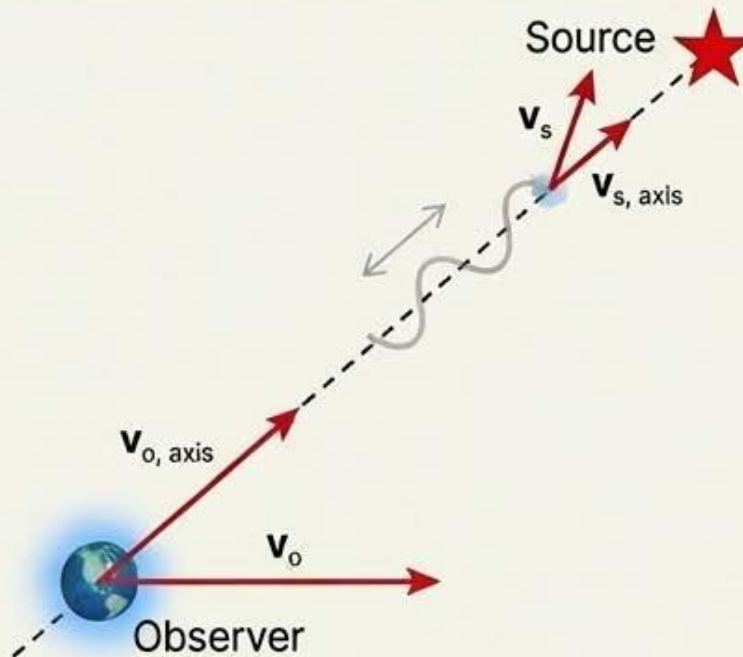
Determined strictly by the source of the wave.

Axiom: Because all colors of light travel at exactly 'c' in a vacuum, determining either frequency or wavelength instantly reveals the other.

Relative Motion: The Axial Rule

The Doppler Distinction

Unlike sound, light does not require a physical medium. The Doppler effect for light relies entirely on the relative velocity between the source and the observer.



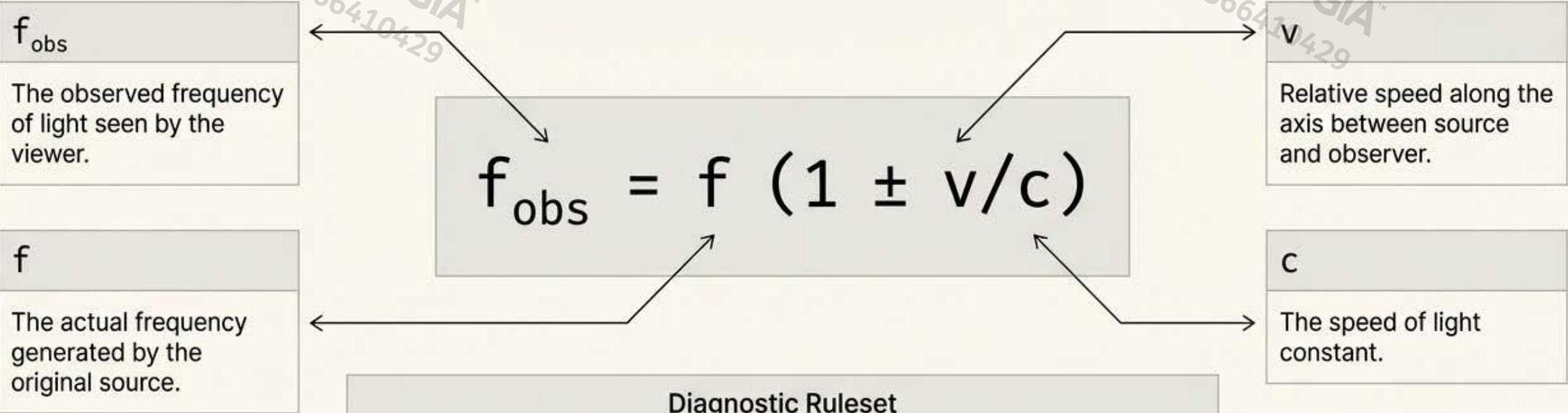
The Axis Constraint

Only the velocity components directly along the straight axis between the source and the observer create a measurable Doppler shift. Lateral movement does not apply.

The Simplification Condition

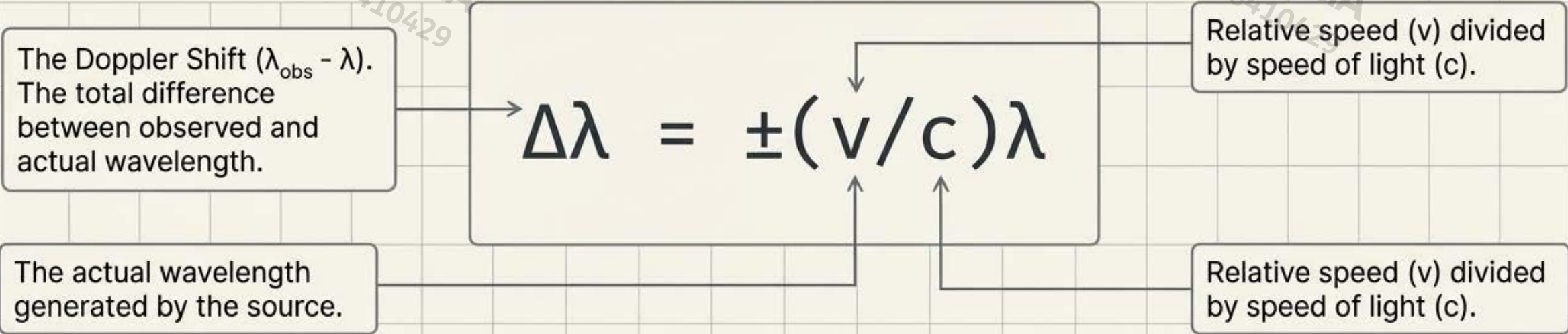
The mathematical models we use assume axial relative speeds are much less than the speed of light ($v \ll c$).

Calculating Observed Light Frequency

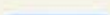


Diagnostic Ruleset How to choose + or -	
+	-
Use (+) if the source and observer are moving TOWARD each other. (Observed frequency increases).	Use (-) if the source and observer are moving AWAY from each other. (Observed frequency decreases).

Calculating Doppler Wavelength Shift



WARNING: Rule Inversion! Because wavelength and frequency are inversely related, the sign rules flip.

Diagnostic Ruleset			
	Use (+) if relative velocity is AWAY . Positive change = longer wavelength (Red Shift).		Use (-) if relative velocity is TOWARD . Negative change = shorter wavelength (Blue Shift).

The Definitive Shift Matrix

A comparative diagnostic tool for exam reference.

Variable / Phenomenon	Red Shift	Blue Shift
Relative Motion	Source moving AWAY	Source moving TOWARD
Wavelength (λ)	Positive Change ($\Delta\lambda$) / Becomes Longer	Negative Change ($\Delta\lambda$) / Becomes Shorter
Frequency (f)	Lower than original source	Higher than original source
Visual Spectrum Impact	Light appearance shifts closer to the red end	Light appearance shifts closer to the blue end

Remember: The speed of light (c) remains perfectly constant in both scenarios.

Analyzing the Stars: Spectrometer Evidence

How Astronomers Measure Speed

- Astronomers observe light from distant galaxies using a spectrometer.
- They look for the specific elemental signatures (like Hydrogen) that exist in labs here on Earth.
- By comparing the laboratory wavelength to the observed galactic wavelength, they can calculate exact velocities.

Visual Evidence

Hydrogen emission spectrum



Redshifted hydrogen emission spectrum



The entire pattern of lines is shifted right toward the red end, proving the galaxy is moving away from Earth.

1929: Edwin Hubble's Revelation

The Observation

Edwin Hubble analyzed light across multiple galaxies. He found that almost all galaxies were sending red-shifted light, no matter what area of the sky he observed.

The Grand Conclusion

Because everything is shifting away from us in all directions, Hubble proved that the universe itself is expanding.

The Cosmic Caveat

While overall expansion is constant, localized gravity matters. Galaxies can still collide and merge depending on their specific sizes and relative speeds.



The Inefficiency of Traditional Solar Tech



The Mechanism

Photovoltaic (PV) cells convert light into electrical current. Incoming light waves strike a semiconductor (**usually silicon**), transferring energy to electrons and forcing them in one direction.

The Critical Flaw

The Sun emits energy across the ENTIRE electromagnetic spectrum. However, silicon PV cells can only absorb the tiny visible light portion. The rest is entirely wasted.

The Result: Residential solar panels capture only **10% to 20% of incoming energy**, requiring massive surface areas to be effective, especially in cloudy climates.

Scientific Breakthrough: STPV Hot Solar Cells

Solving inefficiency by turning wasted heat into targeted light.



Incoming Energy

Broad-spectrum solar energy (including wasted wavelengths) hits the panel.

Thermal Conversion

An absorbing layer of carbon nanotubes concentrates all energy, turning it into extreme heat (up to 1000°C).

Targeted Emission

A layer of nanophotonic crystals takes this thermal energy and converts it back into light—specifically engineered to be the exact wavelengths PV cells can absorb.

Maximized Electricity

The underlying traditional PV cell receives this perfectly-tuned light, generating up to $2\times$ the standard electrical output.

Technology Showdown: PV vs. STPV

Metric	Traditional Photovoltaic (PV)	Solar Thermo-Photovoltaic (STPV)
Primary Mechanism	Direct visible light absorption	Heat conversion & targeted emission
Spectrum Utilized	Only Red to Violet (Visible)	Broad spectrum (Converted via heat)
Operating Temperatures	Ambient / Weather dependent	Extreme heat (Up to 1000°C)
Efficiency / Electrical Output	10-20% of incoming energy	Up to 2x the output of basic PV cells

Impact: STPVs drastically reduce the surface area required for power generation, lowering dependence on nonrenewable fossil fuels even in cloudy climates.

Worked Example: Calculating Galactic Frequency

The Problem Statement

A hydrogen atom in a galaxy moving with a speed of 6.55×10^6 m/s away from Earth emits light with a frequency of 6.16×10^{14} Hz. **What frequency of light would be observed on Earth?**

1. The Given

$$f = 6.16 \times 10^{14} \text{ Hz}$$

$$v = 6.55 \times 10^6 \text{ m/s}$$

Direction = AWAY (This means we use the minus sign for frequency)

$$c = 3.00 \times 10^8 \text{ m/s}$$

2. The Formula

$$f_{obs} = f \left(1 - \frac{v}{c} \right)$$

3. Step-by-Step Solution

$$f_{obs} = (6.16 \times 10^{14}) \times \left[1 - \frac{6.55 \times 10^6}{3.00 \times 10^8} \right]$$

$$f_{obs} = (6.16 \times 10^{14}) \times [1 - 0.02183]$$

$$f_{obs} = (6.16 \times 10^{14}) \times [0.97817]$$

$$\text{Final Answer: } 6.02 \times 10^{14} \text{ Hz}$$

Worked Example: Calculating Wavelength Shift

The Problem Statement

A hydrogen atom in a galaxy moving with a speed of 6.55×10^6 m/s away from Earth emits light with a wavelength of 486 nm. **What wavelength would be observed on Earth?**

1. The Given

$$\lambda = 486 \text{ nm}$$

$$v = 6.55 \times 10^6 \text{ m/s}$$

Direction = AWAY (Use positive sign for wavelength shift)

$$c = 3.00 \times 10^8 \text{ m/s}$$

2. The Formula

$$\Delta\lambda = +(v/c)\lambda$$

$$\lambda_{obs} = \lambda + \Delta\lambda$$

3. Step-by-Step Solution

$$\Delta\lambda = \left[\left(\frac{6.55 \times 10^6}{3.00 \times 10^8} \right) \right] \times 486$$

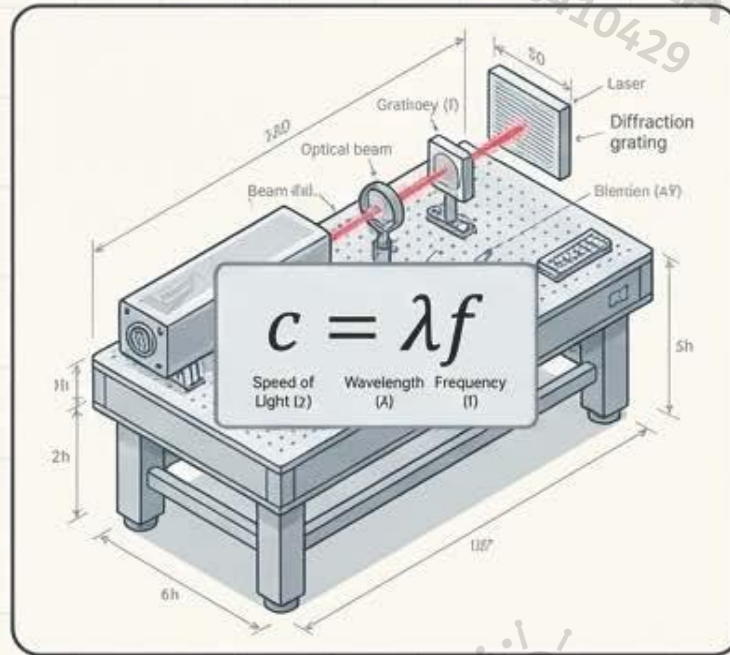
$$\Delta\lambda = (0.02183) \times 486 = 10.61 \text{ nm}$$

$$\lambda_{obs} = 486 + 10.61$$

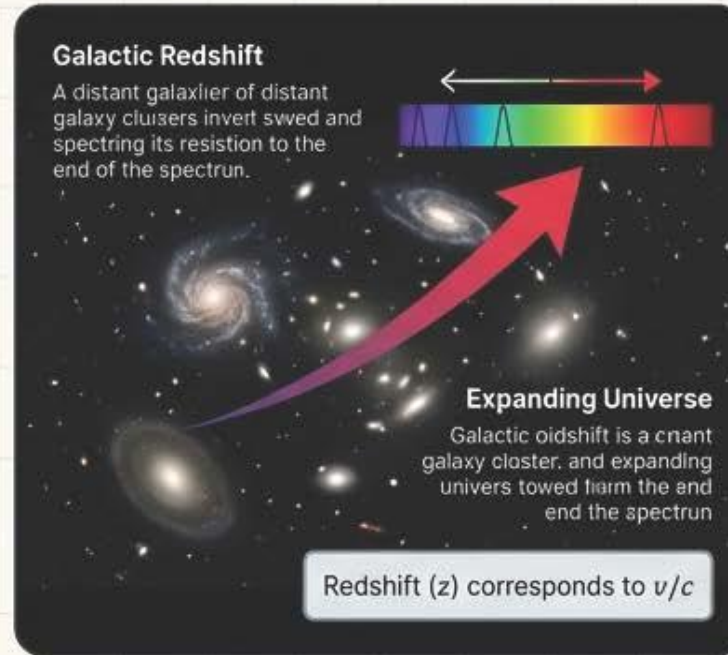
Final Answer: 496.61 nm

The Universality of the Wave Model

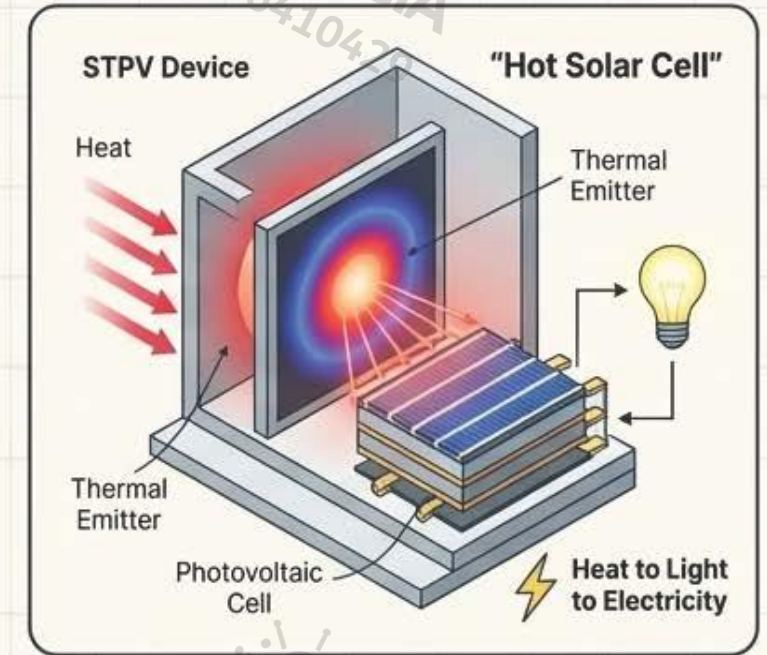
The Micro-Math



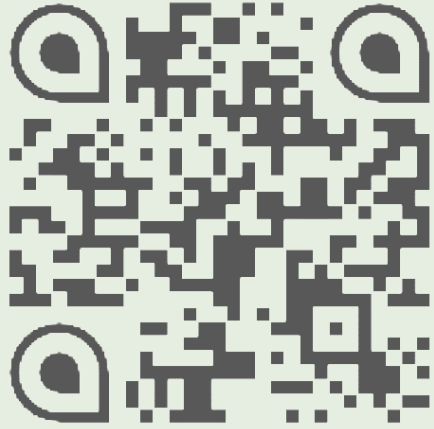
The Macro-Cosmos



The Human Application



The Synthesis: The exact same mathematical relationship that governs a laboratory laser ($c = \lambda f$) allows us to solve the grandest mysteries of the expanding cosmos and engineer the future of human energy. Mastering these core physics equations is the master key to decoding the mechanics of the entire universe.



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ختاماً، نسأل الله أن يوفقكم، وأن
تكون هذه الملزمة قد حققت
الفائدة المرجوة ♥



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